Freshwater Prawn Culture: The Farming of Macrobrachium Rosenbergii

Michael Bernard New
and Wagner Cotroni Valenti

Blackwell Science

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The farming of *Macrobrachium rosenbergii*

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Past-President, World Aquaculture Society

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Dedication

The editors dedicate this book to their families, especially Janet New and Mayla and André Valenti, without whose patience, kindness and encouragement this book could never have been completed.

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Preface

In 1995, one of the editors of this book (MBN) was invited by the other (WCV) to present a keynote paper at a meeting of the Brazilian freshwater prawn farmers' association, Grupo de Trabalho Sobre Camarão de Água Doce (GTCAD), in Vitória. The seed for this book was sown during that meeting, when GTCAD conferred honorary membership on MBN for his contribution to the global development of prawn farming. Active preparation of the manuscript commenced early in 1998 and was completed at the beginning of 2000.

The book is a compendium of information on every aspect of the farming of *Macrobrachium rosenbergii*. Information is also provided about the culture of other *Macrobrachium* spp and the capture fisheries for *M. rosenbergii*. In determining the content of the book and selecting its chapter authors, we decided to provide a summary not only of all facets of the biology and husbandry of *M. rosenbergii* but also of the processing and marketing of the final product. The reader will find that, unusually for a scientific text, the book even includes some recipes for preparing freshwater prawns for consumption. Any type of aquaculture research has little or no value unless a marketable product can be produced, a fact that is sometimes neglected.

This comprehensive review of the status of freshwater prawn farming research, development and commercial practice in the year 2000 is intended to stimulate further advances in the knowledge and understanding of this field. We hope that readers will find our book useful as a reference text and teaching aid. In addition, we trust that those who farm, sell and consume freshwater prawns will find it valuable and interesting. Currently, the importance of ensuring that aquaculture is a responsible and sustainable activity is constantly being stressed. It is therefore particularly appropriate to publish an up-to-date review of the principles of freshwater prawn farming; this form of aquaculture has low environmental impact and offers substantial socioeconomic opportunities.

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April 2000

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The cover illustration is based upon a painting by freshwater prawn-farming pioneer Shao-Wen Ling which was given to Michael New in 1975.

1

History and Global Status of Freshwater Prawn Farming

Michael B. New

This opening chapter briefly describes the origins of modern freshwater prawn (*Macrobrachium rosenbergii*) culture. It continues by recording official and unofficial production data, which emphasise the scale and importance of the sector in many countries as we enter the third millennium. Finally, this chapter summarises a personal view of the future for freshwater prawn farming. Although production data are provided in this chapter, detailed current commercial practices in the various producing countries are described in Chapter 17.

1.1 Origins of modern freshwater prawn culture

Freshwater prawns have been reared in captivity, either through introducing wild-caught juveniles or by trapping them, along with other crustaceans (e.g. *Penaeus* spp. and *Metapenaeus* spp.) and fish, in tidal ponds and paddy fields, for example in the Indian sub-continent and Malaysia (Wickins 1976), from time immemorial. However, modern aquaculture of this species has its origins in the early 1960s. Ling & Costello (1979) and Ling (1977) recalled that experiments on the rearing of prawn larvae had been conducted by fisheries biologists all over the world but had been unsuccessful before then. In 1961 a major breakthrough was achieved at the Marine Fisheries Research Institute in Penang, Malaysia, when the Food and Agriculture Organization (FAO) expert Shao-Wen Ling (Fig. 1.1) discovered that freshwater prawn (*M. rosenbergii*) larvae required brackish conditions for survival.

Dr Ling's poignant description of his first experiments (Ling 1977), which included his observations that successful mating (rather than the previously observed cannibalism) occurred when the females underwent a pre-mating moult, is part of the folklore of aquaculture. This pioneer then discovered, through trial and error, that the addition of salt or soy sauce proved a key to larval survival: freshwater prawn larvae need brackishwater to survive beyond 5 days. This had not been realised before because the mature adult prawns had been collected in totally freshwater, sometimes up to 100 miles (160 km) distant from the sea. This observation quickly led to the rearing of larvae through all their developmental stages in 1962, as first described by Ling & Merican (1961), and the production of sufficient juvenile prawns to initiate grow-out experiments in ponds in 1963 (Ling & Costello 1979). News of this success spread rapidly and generated worldwide interest in freshwater prawn culture. Within 10 years, research and development projects had commenced in most Asian countries, as well as in Europe, the Americas and Africa.

While Ling's discoveries were fundamental, it was the work of another pioneer, Takuji Fujimura (Fig. 1.2), that made the commercial development of freshwater prawn culture possible. His research in Hawaii commenced in 1965, with the introduction of broodstock of *M. rosenbergii* from Malaysia (Ling & Costello 1979). Lee (1979) provided a detailed account of the early days of prawn farming in Hawaii. Within 3 years, the work of Fujimura and his team in the Anuenue Fisheries Research Center in Honolulu developed mass-rearing techniques for commercial-scale hatchery production of prawn

Fig. 1.1 Shao-Wen Ling, who first completed the life cycle of *Macrobrachium rosenbergii*. (Source: Chew, 1990; courtesy of the World Aquaculture Society.)

postlarvae (PL) (Fujimura & Okamoto 1972). Following the ready availability of PL for stocking, grow-out experiments spawned commercial farms in Hawaii and elsewhere throughout the 1970s. In Asia, both Thailand and Taiwan (Chen 1976) were initiating what has since become a significant industry in both countries.

Further details about the life of Shao-Wen Ling (Chew 1990) and Takuji Fujimura (Wong & Brock 1991), who both died in 1990, were given in tributes published by the World Aquaculture Society (WAS). The World Aquaculture Society had granted honorary life membership of the Society to these two ‘fathers’ of freshwater prawn farming in 1974 (Shao-Wen Ling) and 1979 (Takuji Fujimura).

Fig. 1.2 Takuji Fujimura (second from the left), who pioneered the large-scale hatchery production of *Macrobrachium rosenbergii*. (Source: Wong & Brock, 1991; courtesy of the World Aquaculture Society.)

Based on the success of the Hawaiian hatchery and grow-out research and commercial experiences, broodstock were introduced, both from Southeast Asia and from Hawaii, into many countries where *M. rosenbergii* was not indigenous. Introductions occurred notably in North, Central and South America, but also in Africa, and even (for experimental environmentally controlled culture in temperate regions) in Europe. Takuji Fujimura himself played a key role in many of these developments, not only in arranging the supply of broodstock but also, more significantly still, by providing training in the technology his team had developed. This essential education was provided both in Hawaii and through the consultancy work conducted by Fujimura around the globe during the 1970s and 1980s.

Some examples of initial introductions of *M. rosenbergii* are provided in Table 1.1. Though further introductions have occurred in some countries, usually from farm pond or research sources, it seems likely that much of the prawn culture in countries where *M. rosenbergii* is not indigenous

Table 1.1 Examples of introductions of freshwater prawns (*Macrobrachium rosenbergii*) for farming purposes.

Country where introduced	Date	Source	Reference
Argentina	1986	Brazil	Weidner *et al*. (1992b)
Australia[a]	?	Malaysia	Ling & Costello (1979)
Brazil	1977	Hawaii	Cavalcanti (1998)
China	1976	Thailand	Yixiong & Suzhi (1995)
Colombia	?	Hawaii	Ling & Costello (1979)
Dominica	1984	Guadeloupe and French Guiana	Weidner *et al*. (1992a)
French Guiana	1979	Martinique	Lacroix *et al*. (1994)
Honduras	?	Hawaii	Ling & Costello (1979)
Iran	1990	Bangladesh	W.G. Yap (pers. comm. 1992)
Israel	?	Thailand	Ling & Costello (1979)
Italy	1984	USA	Wildman *et al*. (1992)
Jamaica	?	Hawaii	Ling & Costello (1979)
Japan	1967?	Malaysia	Ling & Costello (1979)
Martinique	1977	Mauritius	Lacroix *et al*. (1994)
Mauritius	1972	Hawaii	Cox (1973)
Mexico	?	Hawaii	Ling & Costello (1979)
Paraguay	1988	Brazil	U. Wijkstrom (pers. comm. 1992)
Puerto Rico	1975	Hawaii	Lacroix *et al*. (1994)
Singapore	?	Malaysia	Ling & Costello (1979)
Suriname	1985	French Guiana	R.H. Power (pers. comm. 1985)
Taiwan	1970	Thailand	Hsieh *et al*. (1989)
United Kingdom	1966	Malaysia	Goodwin & Hanson (1975)
Uruguay	1984	Panama	Weidner *et al*. (1992b)
USA (Hawaii)	1965	Malaysia	Fujimura (1966)
USA (other States)	1960s	Hawaii	Ling & Costello (1979)

[a] The species is also indigenous in this country.

is based on a very small initial broodstock. This makes the industry in those countries vulnerable to genetic degradation, a phenomenon which has been observed in commercial farms in Taiwan, for example. The huge industry in China has recognised this danger and regularly introduces new broodstock from abroad. Genetic degradation has also been observed in countries where this species is indigenous but broodstock are obtained only from grow-out ponds, rather than the capture fisheries.

The third important milestone in the history of freshwater prawn farming occurred when the United Nations Development Programme (UNDP) decided to fund an FAO-executed project, named 'Expansion of Freshwater Prawn Farming', in Thailand. This project built on the existing work of the Thai Department of Fisheries, led by Somsak Singholka and his team at the Chacheongsao Fisheries Station in Bangpakong, Chonburi. The work of the project was initiated by Somsak Singholka, with the help of Takuji Fujimura (Fujimura 1978), and a visiting FAO project manager, Herminio Rabanal, in 1978. Following the recruitment of Michael New by the FAO in 1979, he and Somsak Singholka managed this project jointly until 1981, after which the Thai government continued this initiative. Here, as in Hawaii, the major stimulus for the development of prawn farming was the provision not only of technical advice but also of free PL for stocking the initial commercial grow-out operations on each farm. Freshwater prawns were soon being distributed all over Thailand. Farmed freshwater prawn production expanded from less than 5 t in 1976 to an estimated 400 t in 1981 (Boonyaratpalin & Vorasayan 1983). By 1984, annual Thai production had exceeded 3000 t (FAO 1989).

This alone was a significant development within Thai aquaculture. However, this project also generated information for a technical manual (New & Singholka 1982, 1985) which the FAO published in

English, French and Spanish and which was translated by others into Vietnamese and Farsi. In addition, several workshops, conferences and reviews made important contributions to the early development of freshwater prawn farming. A leaflet on this topic was published in England (Forster & Wickins 1972) and this subject, combined with marine shrimp biology and culture, was reviewed by Wickins (1976). Workshops on freshwater prawn farming in the western hemisphere were held in 1974 and 1976. A summary of the proceedings of the 1974 meeting was published (Goodwin & Hanson 1975) and the proceedings of the second workshop in the USA formed part of a book by Hanson & Goodwin (1977), which included one of the earliest bibliographies on the biology and culture of *Macrobrachium* spp. (Trimble & Sandifer 1977). An international conference on this topic was held in Vietnam in 1975, in which Takuji Fujimura also had a hand.

However, 'Giant Prawn 1980' was probably more influential in stimulating further global research and development, commercial farming, and personal contacts in this field than any other conference. With the aid of the FAO project on the expansion of freshwater prawn farming, the Thai Department of Fisheries hosted this meeting, the first international aquaculture conference ever held in Thailand (New 1982). One hundred and fifty nine participants attended from 33 countries, and a further 200 local farmers participated in a special session in the Thai language. One of the two original *Macrobrachium* pioneers, Takuji Fujimura, by then working in Hong Kong, was an active chairman of the discussions on practical prawn farming. The other, Shao-Wen Ling, though unable to attend personally, sent a welcoming address.

'Giant Prawn 1980' was convened by the author of this chapter, and was attended by several of its other chapter authors, namely Sterling (Ken) Johnson (Chapter 15), Spencer Malecha (Chapter 16), and Patrick Sorgeloos (Chapter 7), and others who have contributed information for this book, especially Chapter 17. Participants in 'Giant Prawn 1980' also included others who led freshwater prawn farming developments, including Bill Fitzgerald (Guam), I-Chiu Liao and Nai-Hsien Chao Liao (Taiwan), Lee Chan Lui (Malaysia), Rogene Thompson and Jean-Marie Huron (Mauritius), Paul Sandifer (USA), and many colleagues from Thailand. Quite recently, a participant from Myanmar, Nyan Taw, stated that 'commercial farming of freshwater prawns actually started to take off in 1980 after the first international aquaculture conference "Giant Prawn 1980"' (Taw 1997). Unfortunately, the proceedings of this meeting (New 1982) are now out of print.

Since that time, in addition to the FAO manual already mentioned, which is still in print (New & Singholka 1985), many other manuals have been issued (e.g. Valenti 1985; Cavalcanti *et al.* 1986; Hollshmit 1988; Gray 1990a,b; Griessinger *et al.* 1991; Chowdhury *et al.* 1993; Sebastian *et al.* 1993). Freshwater prawn farming has been reviewed in a number of other publications (e.g. New 1990, 1995, 1998; Valenti 1990, 1998; Brown 1991; Lee & Wickins 1992; McVey 1993) and further conferences specifically devoted to this topic have been held, for example in India (Silas 1992; Thakur *et al.* 1994) and in Brazil in 1995 (see the Preface to this book). In addition to the people mentioned above, and the teams that worked with them, many other people were early pioneers in the introduction of commercial freshwater prawn (*M. rosenbergii*) culture around the tropical world, including J.D. Ardill (Mauritius), Lourinaldo Cavalcanti (Brazil), Dan Cohen and Adrian Barnes (Israel), Michael Fujimoto and Dale Sarver (Hawaii), Roy Jenson (Martinique), Somphong Suwannatous and Piamsak Menasveta (Thailand), and Nyan Taw (Myanmar), and others whose names will be found in the reference lists of our book.

In the western hemisphere a number of activities, which aimed at exploring the possibility of intensive freshwater prawn farming in temperate areas, including Europe and the USA, were begun in the 1960s. *Macrobrachium rosenbergii* was introduced into England in 1966 by the economist Keir Campbell, with whom the author of this chapter worked from 1969 to 1971, when Ranks Hovis McDougall (a flour, bakery and animal feedstuff manufacturer) was exploring the potential of its culture under environmentally controlled conditions. These studies proceeded in parallel with the research of John Forster, Terry Beard and John Wickens in the Ministry of Agriculture, Fisheries and Food laboratory in Wales (Goodwin & Hanson 1975). In 1972 the present author (MBN) initiated similar work for a pharmaceutical company, Syntex, in California and in Mexico, where Mike Choudhury (later FAO aquaculture specialist in Bangkok) was also involved. The author's Syntex team continued these studies under the leadership of Ed McSweeny. However, while environmentally controlled culture proved technically feasible, the cost of heat made it economically inadvisable and attention mainly reverted to semi-intensive farming in tropical areas. One exception has been the interest in the culture of freshwater prawns using thermal waters which has been exhibited in a number of countries, including Italy and the USA; however, New Zealand is the only country where this activity has become commercial (Chapter 17).

Another exception has been the development of *M. rosenbergii* farming in temperate areas where summer temperatures in open ponds are sufficiently high. Following the early work of Paul Sandifer and his team in South Carolina, this has shown commercial potential in the USA (Chapter 11). Much of the substantial production of freshwater prawns from aquaculture in China comes from areas where the grow-out of *M. rosenbergii* is only feasible in summer months, or from the culture of *M. nipponense*, which is more tolerant of lower temperatures (Chapter 17). There is also a limited grow-out season in some regions of other producing countries, for example in the South and part of the Southeast of Brazil.

Despite these research and commercial initiatives, a considerable proportion of global freshwater prawn farmed output still originates from areas where year-round grow-out is feasible, such as the Indian sub-continent, Southeast Asia and the tropical areas of Latin America. The expansion of commercial freshwater prawn farming (see section 1.2) has been aided by many individual research workers and developmental projects. Their achievements are numerous and have included the development of practical recirculation systems for hatcheries, improved understanding of the management of the heterogeneous prawn populations in grow-out ponds, and a recognition of the special requirements of freshwater prawns during harvesting and processing to ensure that only high-quality products reach the market. The other chapters of this book are devoted to recording these and many other developments in this field which occurred in the final two decades of the 20th century.

1.2 Global production status

The first recorded global data (FAO 1989) for farmed giant river prawn (*Macrobrachium rosenbergii*) production were 5246 t in 1984. At that time, FAO aquaculture statistics did not include value data. By 1989, global production was more than three times as great, at 17 608 t (FAO 2000) with a value of about US$ 75 million. However, production then appeared to plateau, averaging 21 013/yr in the years 1990–1995 inclusive, with a low of 18 185 t in 1993 and a high of 26 696 t in 1991 (Table 1.2). The high figure in 1991 corresponded with the peak output from Taiwan (16 196 t, nearly 61% of the global total); from 1992 to 1998, Taiwanese production has been substantially lower (see Chapter 17) and only exceeded 8000 t twice, in 1995 and 1998.

The first major change in the global picture became obvious in 1998, when China began to submit separate statistical returns for farmed *M. rosenbergii* (FAO 1998). This showed that Chinese production had already exceeded 37 000 t by 1996 (Table 1.2). In the following 2 years, further substantial expansion in Chinese production occurred, to nearly 43 000 t in 1997 and approaching 62 000 t in 1998. The second major event occurred in 2000, when the FAO released data (FAO 2000) showing that Bangladesh had at last begun to provide separate data for farmed *M. rosenbergii* which indicated that production was 48 000 t for both 1997 and 1998 (Table 1.2). Production in India expanded significantly between 1996 and 1998, albeit at a fraction of the scale of China and Bangladesh. However, output remains static in the other major Asian reporting countries, Taiwan and Thailand. Vietnam is a special case, as discussed below.

There has been no corresponding increase in the production of farmed *M. rosenbergii* in other regions of the world. Indeed, production in both Central America (including the Caribbean) and South America showed a significant decline from its peak in 1994 until 1998. In Central America, this was mainly because reported production from the Dominican Republic in 1998 was less than one-tenth of that in 1994. In South America, the decline has been less marked than in Central America but official data indicate that production has declined in Brazil and Peru.

Table 1.2 Farmed freshwater prawn (*Macrobrachium rosenbergii*) production (in metric tons) 1989–98[a]. (Source: FAO, 2000.)

	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Africa	74	67	67	77	70	98	97	96	84	66
Malawi	6	6	3	3	5	5	5	+	+	+
Mauritius	50	42	47	55	42	63	53	62	44	28
Réunion	2	2	3	3	3	4	4	4	4	3
Senegal	3	2	2	6	10	11	20	25	21	20
Zimbabwe	13	15	12	10	10	15	15	15	15	15
Central America	426	440	376	772	1 180	1 411	398	365	375	397
Costa Rica	7	7	7	7	10	13	15	78	78	86[b]
Dominica	–	–	–	4	1	2	2	2	3	3
Dominican Republic	50	50	43	164	739	961	86	90	90	87
El Salvador	1	4	7	8	9	9	10	10	14	12
Grenada	–	–	–	–	–	–	+	+	+	+
Guadeloupe	44	42	44	35	40	26	30	30	20	14
Guatemala	8	10	7	35	32	76	99	5	75	52
Honduras	+	+	+	+	+	+	+	+	+	+
Jamaica	30	30	30	30	50	55	60	60	60	65
Martinique	57	49	52	38	42	40	40	35	44	25
Panama	5	6	8	5	5	+	3	2	1	+
Puerto Rico	224	242	172	439	246	221	45	45	45	45
St Lucia	+	+	+	1	+	1	1	1	1	1
Trinidad & Tobago	. . .	. . .	6	6	6	7	7	7	7	7
North America	512	385	323	314	334	283	92	90	112	37
Mexico	353	201	139	167	175	124	92	90	112	37
USA	159	184	184	147	159	159	. . .	. . .	. . .	. . .
South America	1 615	1 620	1 568	1 580	1 593	1 798	1 284	1 367	1 328	1 363
Argentina	–	–	–	2	7	13	12	20	22	20
Brazil	700	600	550	650	700	700	341	486	446	480
Colombia	50	60	30	55	10	10	–	–	–	–
Ecuador	764	849	870	850	850	850	800	800	800	800
French Guiana	89	83	83	–	–	–	–	–	7	18
Peru	10	5	4	1	1	212	100	31	23	45
Suriname	+	+	+	+	+	+	+	+	+	+
Venezuela	2	23	31	22	25	13	31	30	30	. . .
Asia	14 959	18 451	24 343	18 529	14 915	17 043	16 343	53 014	107 107	127 627
Bangladesh	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	48 000	48 000
Brunei	+	+	+	1	+	+	+	+	+	–
China	. . .	. . .	. . .	. . .	. . .	. . .	. . .	37 363	42 851	61 868
India	150	198	196	455	178	311	. . .	178	753	1 507
Israel	3	3	3	3	3	3	+	+	+	+
Malaysia	128	137	145	94	52	46	79	114	143	281
Myanmar	4	3	3	5	3	3	5	5	6	6
Taiwan	6 725	11 607	16 196	7 665	5 475	6 556	8 467	7 354	7 554	8 165
Thailand	7 949	6 503	7 800	10 306	9 204	10 124	7 792	8 000	7 800	7 800
Pacific	22	19	19	17	93	95	97	98	45	43
Fiji Islands	1	2	4	6	85	87	91	93	40	40
French Polynesia	20	17	15	11	8	8	6	4	4	2
Guam	+	+	+	+	+	+	+	+	+	+
New Caledonia	1	+	+	+	+	+	+	+	+	+
Solomon Is	+	+	+	+	+	+	+	1	1	1
Totals										
Metric tons (t)	17 608	20 982	26 696	21 289	18 185	20 728	18 311	55 040	109 051	129 533
US$ million	75.2	113.0	140.8	105.6	119.2	145.5	146.0	238.8	749.7	795.1

Notes:

[a] + = more than zero but less than 0.5 t; – = no production recorded; . . . = data not available.

[b] The production figure which Costa Rica reported to FAO for 1998 (FAO 2000) was 866 t. However, the author of this chapter believes that this was the result of a typographical error. There is only one farm in Costa Rica (see Chapter 17). Production has therefore been entered in this table as 86 t, and the Central American and global production totals adjusted accordingly. An adjustment in the FAO figure for global value has also been made. Otherwise, all data are as presented in FAO (2000).

Table 1.3 Production (in metric tons) of farmed freshwater prawns and shrimps not elsewhere included (Palaemonidae), 1989–98. (Source: FAO, 2000.)

	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Cuba	752	1206	1374	1004	802	1136	1448	1315	2005	2000
Guatemala	–	–	–	–	–	10	9	9	2	2
Japan	32	34	19	20	21	21	15	13	12	14
Totals										
Metric tons (t)	784	1240	1393	1024	823	1167	1472	1337	2019	2016
US$ million	2.2	3.5	3.9	2.9	2.5	3.6	5.2	4.7	6.9	6.9

— = no production recorded.

Table 1.4 Production (in metric tons) of farmed freshwater crustaceans not elsewhere included (Crustacea), 1988–98. (Source: FAO, 2000.)

	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Bangladesh	24542	24493	25080	27298	29130	50260	58973	59560	21035	21035
Russia	–	–	–	1	1	7	20	3	10	15
Vietnam	9000	10000	11000	12000	12000	12500	16500	13200	23800	25600
Totals										
Metric tons (t)	33542	34493	36080	39299	41131	62767	75493	72763	44845	46650
US$ million	251.6	258.7	276.1	300.7	320.5	458.1	545.0	515.9	207.6	218.6

– = no production recorded.

To date, farmed *M. rosenbergii* production data have not been reported separately by Cuba and Japan, which have included them in the FAO statistical category 'freshwater prawns and shrimps not elsewhere included (Palaemonidae)' (Table 1.3). Similarly, the Russian Federation and Vietnam have included farmed *M. rosenbergii* within the FAO category 'freshwater crustaceans not elsewhere included (Crustacea)' (Table 1.4). Guatemala makes statistical returns both specifically for *M. rosenbergii* (Table 1.2) and also under the general category 'freshwater prawns and shrimps not elsewhere included (Palaemonidae)' (Table 1.3). The latter category may include other farmed *Macrobrachium* spp. Vietnam is a major farmed freshwater prawn producing country and it is certain that a significant proportion of its estimated production of farmed freshwater crustaceans (Table 1.4) consists of *M. rosenbergii*. Thus, the specific FAO data for the global aquaculture production of *M. rosenbergii* are necessarily an underestimate. In addition to the farming of this species, commercial culture of other *Macrobrachium* spp. is either nascent or, in the case of *M. nipponense*, is already substantial in scale (Chapter 21). To date (2000), no official data have been submitted to the FAO for these freshwater prawn species. By 1998, the farmed production of *M. nipponense* was already cited as being at least 15000 t/yr (Chapter 21) and may have been much higher than that (Chapter 17).

Using the specific FAO data on *M. rosenbergii* (FAO 2000), it appears that over 98% of global farmed production of *M. rosenbergii* in 1998 was reared in Asia, while South America and Central America (including the Caribbean) are the other major producing regions. The five major producing countries (Table 1.2) are China (48% of 1998 global production), Bangladesh (37%), Taiwan (6%), Thailand (6%), and India (1%). According to the FAO data, the production of only three other countries exceeded 100 t in 1998: Ecuador (800 t), Brazil (480 t), and Malaysia (281 t). The omission of another major producer from this 'league' (Table 1.2), namely Vietnam, has been explained above. Unofficial estimates (see Chapter 17) indicate that the production of farmed *M. rosenbergii* in the Mekong delta region of Vietnam was at least 3000 t in 1998. In addition, actual production in India was probably significantly higher than the official data submitted to the FAO, perhaps as high as 5000 t in 1998 (Chapter 17). Further substantial aquaculture production of other freshwater prawn species, mostly *M. nipponense*, has also occurred but has not yet appeared in the aquaculture statistical returns made by the Member States of the FAO.

In summary, it is clear that freshwater prawn farming has already become a major contributor to global aquaculture, both in terms of quantity and, even more so, value. By 1998 (the last year for which official statistics were available when this chapter was written), the annual global production of farmed *M. rosenbergii* alone had already reached nearly 130 000 t, with a value of almost US$ 800 million. This does not include contributions from those countries that do not provide separate data for this species, notably Vietnam, or take account of recent information which indicates that production may be being underestimated in some countries. It also does not include the production of other *Macrobrachium* spp. The farming of *M. rosenbergii* alone had almost certainly become a billion dollar industry by the year 2000. Further expansion in the last 2 years of the 20th century and the inclusion of the production of other freshwater prawn species, which so far has either been unreported or obscured in more general statistical categories, is expected to result in the contribution of this type of aquaculture reaching 200 000 t/yr early in the new millennium.

1.3 Summary of opportunities and constraints

1.3.1 Opportunities

A number of factors favour the development of freshwater prawn farming:

- In contrast to most forms of marine shrimp culture, freshwater prawn farming does not require coastal sites, either for hatcheries or grow-out. Coastal hatcheries still exist but are not mandatory. Most hatcheries are now inland, using trucked seawater or brine, or artificial seawater, and often minimising their use by recirculation systems.
- With currently available technology, freshwater prawns cannot be reared in grow-out systems as intensively as marine shrimp. While this has often been regarded as a constraint by investors in the past, it may be an advantage for reasons of sustainability (see Chapter 23).
- There is no shortage of egg-carrying females for hatcheries and, if the development of a captive broodstock is shown to be advisable for stock improvement, mating and spawning can easily be achieved in captivity.
- Freshwater prawn farming is suitable for both large-scale and small-scale commercial rearing units. In addition, it is suitable for very small artisanal production units, which are often a target of government policies designed to favour riverine and other communities in poor regions.
- Freshwater prawns are suitable candidates for inclusion in polyculture systems, and in integrated aquaculture-agriculture. There is potential for freshwater prawns to occupy the bottom of countless hectares of tropical and sub-tropical fish ponds around the world, providing an opportunity for fish farmers to increase production and profit with little extra investment and at no cost to the environment.
- Export opportunities for freshwater prawns exist. Peeled, mostly wild-caught, *M. rosenbergii* have long been exported globally but, unlike 20 years ago, shell-on (and often head-on) freshwater prawns are now a familiar sight in the supermarkets of Europe. To a lesser extent, this also occurs in the USA (mainly for consumption by Asians or in restaurants serving Asian food) and Japan. As noted later in Chapter 17, Bangladesh, Vietnam and Thailand already export a significant proportion of their wild-caught and farmed prawns. Potential for expansion exists but producers will need to co-operate in collective marketing to exploit these opportunities. Freshwater prawns are a product that is distinct from marine shrimp, with its own favourable culinary characteristics (Chapter 19). The unique characteristics of the product require further image development.

1.3.2 Constraints

Some real or perceived factors inhibit the development of freshwater prawn farming:

- The time that freshwater prawns (*M. rosenbergii*) spend in the hatchery phase is about twice as long as for marine shrimp. However, the larval cycle of other species (e.g. *M. nipponense* and *M. amazonicum*, which are discussed in Chapter 21) is shorter.
- As noted above, freshwater prawns cannot be reared in grow-out systems as intensively as marine shrimp. This has often been regarded as a constraint by investors in the past but it may be an advantage for reasons of sustainability (see Chapter 23).
- In the past, freshwater prawn culture was seen as suitable mainly as a source of products for domestic consumption in countries where it had market familiarity. This contrast to marine shrimp farming, which supplies a well-structured global market, mainly in 'developed' countries, has deterred some investors who seek to maximise foreign exchange earnings. However, as noted above, this constraint is not as great as often imagined.
- Freshwater prawns require more care in processing than marine shrimp. This is only a constraint when this fact is not recognised by producers and processors, and poor-quality products are allowed to enter the marketplace. Simple precautions can ensure that premium-quality freshwater prawns are offered for consumption (see Chapters 18 and 19).
- Some countries that are ideal for production but whose farming costs are high, suffer from competition from 'cheap' imported freshwater prawns. Though this is a constraint for individual producers, the quality of locally produced prawns achieves a premium price. Globally, this phenomenon is not seen as important. Like any other commodity, prawn farming is subject to economic and market pressures.

1.3.3 Prognosis

Bearing both positive and negative factors in mind, it is believed that freshwater prawn farming has a bright future but the level of global production may never rise so high as that from marine shrimp farming. Further research (as indicated in other chapters of this book), and the more effective transfer of improved rearing and processing technology, is needed in order to exploit the opportunities for expansion in this sector of the aquaculture industry.

New & Csavas (1993) predicted that Asian freshwater prawn production would rise to nearly 68000t by the year 2000. New (1995) anticipated that the earlier forecast for Asia might be rather conservative and believed that a global production exceeding 70000t by the year 2000 was feasible if those countries with suitable sites and environment, and relatively cheap labour, could take advantage of the domestic and export market potential. In retrospect, both forecasts proved to be extremely conservative. Expansion was expected mainly in Bangladesh and India but the development (and rapid expansion) of *M. rosenbergii* farming in China was not anticipated. Substantial production expansion indeed occurred in Bangladesh, and is commencing in India, but production from China is currently dominant (Table 1.2). The output from Chinese farming is consumed entirely domestically. Bangladesh and India, as well as Thailand and Vietnam, may be better placed than China to develop their export trade in farmed *M. rosenbergii*.

The net result of recent developments in global freshwater prawn culture is that the highest forecasts for the year 2000 by New (1995) and New & Csavas (1993) had already been massively exceeded by the year 1998. Asia was the predominant producing region at the end of the second millennium and its output was expected to continue increasing, probably at an accelerating rate. The potential for the expansion of freshwater prawn farming in other regions, notably in South and Central American countries but also in Africa, while substantial and technically feasible, remains an opportunity yet to be seized. It is hoped that investors and exporters in these regions will exploit this opportunity as we enter the third millennium, particularly as the further expansion of marine shrimp farming has many social and environmental constraints.

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2
Nomenclature and Taxonomy

Lipke B. Holthuis

This chapter concentrates on the nomenclature and taxonomy of the genus, set in an historical perspective. The morphology of larval and immediate post-larval prawns and the biological function of the external features of the species are discussed in Chapter 3.

2.1 The genus *Macrobrachium* in aquaculture

The freshwater prawns that have been used so far in aquaculture and aquaculture experiments all belong to the genus *Macrobrachium* Bate, 1868. This is the largest genus of the family Palaemonidae Rafinesque, 1815 (superfamily Palaemonoidea Rafinesque, 1815; infra-order Caridea Dana, 1852; sub-order Natantia Boas, 1880; order Decapoda Latreille, 1803); about 200 species have been described in this genus. Almost all of these live in freshwater, at least for part of their life. The genus is circumtropical and native to all continents except Europe.

Until recently, most commercial culture had been based on *Macrobrachium rosenbergii* (De Man, 1879), the species with which most of the present volume is concerned. However, China is now culturing large quantities of *M. nipponense* (De Haan, 1849) (see Chapters 1 and 17); this species, which is also native to Japan, Taiwan and Vietnam, has been introduced into the Russian Federation, the Philippines and Singapore.

A number of other species of *Macrobrachium* have been used for aquaculture experimental work: *M. acanthurus* (Wiegmann, 1836), from Atlantic America: North Carolina to South Brazil; *M. amazonicum* (Heller, 1862), from Atlantic South America: Venezuela to South Brazil; *M. americanum* Bate, 1868, from Pacific America: Baja California to North Peru; *M. carcinus* (Linnaeus, 1758), from Atlantic America: Florida to South Brazil; *M. formosense* Bate, 1868, from Japan and Taiwan; *M. lamarrei* (H. Milne Edwards, 1837), from India and Bangladesh; *M. lanceifrons* (Dana, 1852), from the Philippines; *M. lanchesteri* (De Man, 1911), from Thailand, Malaysia and Singapore; *M. lar* (Fabricius, 1798), inhabiting the entire Indo-West Pacific region from East Africa to Polynesia; *M. malcolmsonii* (H. Milne Edwards, 1844), from Pakistan, India and Bangladesh; *M. ohione* (Smith, 1874), from Atlantic USA: Virginia to Texas, and the Mississippi basin; *M. rude* (Heller, 1862), from East Africa to Bangladesh; and *M. vollenhovenii* (Herklots, 1857), from West Africa: Cape Verde Islands to South Angola.

Of these species most are not cultured anymore, and some only on a very small scale. There are recent reports of experiments and small-scale culture of *M. americanum*, *M. carcinus* and *M. vollenhovenii.* These three species are closely related and are easiest recognised by their region of origin (West America, East America and West Africa, respectively). They are of a rather large size (170–250 mm total length), but are smaller than *M. rosenbergii* from which they further differ by the short rostrum, which is rather straight and has 2 to 5 (mostly 3 or 4) ventral teeth and 11 to 14 dorsal teeth; the large chelae are far less slender with the carpus (the segment before the chela) shorter than the preceding segment, the merus; the movable fingers do not show a velvety pubescence. The external morphology of *M. rosenbergii* is described in Chapter 3.

Three other species which at present are cultured on a small scale or experimented with are *M. lanchesteri*, *M. acanthurus* and *M. malcolmsonii.* They resemble *M. rosenbergii* in having the second legs of the male very slender with the carpus distinctly longer than the merus; in all three both fingers of the second chela of the adult male shows a dense pubescence. The rostrum of these three species reaches at most a little beyond the antennal scale. *Macrobrachium lanchesteri* is a rather small species (total length up to 55 mm), with a straight rostrum, bearing 6 to 11 (usually 8 or 9) dorsal and 2 to 7 (usually 3 or 4) ventral teeth. *Macrobrachium acanthurus* is much larger (up to 166 mm), and much more robust; its rostrum has 9 to 11 dorsal teeth and 4 to 7 ventral. *Macrobrachium malcolmsonii* is of pretty good size (up to 230 mm). It is closer to *M. rosenbergii* than the other species mentioned here, but as already mentioned the second legs of the adult male have both fingers covered with a velvety pubescence, and the rostrum, though showing a dorsal crest over the orbits, is shorter, less slender and has only about 5 ventral teeth.

2.2 Nomenclature and historical perspective

Macrobrachium rosenbergii was one of the first species of the genus to become known to western science. The first recognisable figure of it was published (as Figure B of Plate 1) in 'D'Amboinsche Rariteitkamer' (Rumphius 1705). However, this excellent figure did not belong to Rumphius' original manuscript, but was added later by the editor, Simon Schijnvoet, who wanted the book more richly illustrated; to that end he had figures made of a number of specimens in the many Dutch cabinets of natural curiosities of that time. Most of these additional specimens did not originate from Ambon (Moluccas, Indonesia), the site of Rumphius' researches, and usually were not labelled as to their original locality. Fortunately, such additional illustrations were carefully indicated as such in the text. Figure B of Plate 1 in that volume was made after a specimen in the collection of Henricus d'Acquet (1632–1706), a physician who was burgomaster of Delft and had a very rich natural history cabinet. The original figure, reproduced in this chapter of our book as Fig. 2.1, is still extant and is held by the Instituut voor de Tropen (Institute for the Tropics) in Amsterdam. It is of good quality, but unfortunately it is not provided with a legend, so that the origin of the depicted animal is unknown.

The first good written account of the species is provided by Herbst (1792), who gave a good description and an illustration (as Figure 1 of his Plate 28) under the incorrect name *Cancer (Astacus) carcinus* Linnaeus, 1758. Linnaeus' *Cancer carcinus*, namely, is an American species of *Macrobrachium*, which Herbst (1792) described and illustrated (as Figure 2 of his Plate 27) as a new species under the name *Cancer (Astacus) jamaicensis*. Herbst's descriptions and illustrations so clearly characterised the two species that his nomenclature was adopted by most subsequent authors and, during the following 150 years, the specific name *carcinus* was generally used for the present East Indian species and that of *jamaicensis* for the American. The first who challenged this nomenclature was Sunier (1925), who showed that Linnaeus' description of *Cancer carcinus* was solely based on material of the American species named *jamaicensis* by Herbst (1792). Sunier (1925) accepted the consequences of his discovery and replaced the name *jamaicensis* by *carcinus*, and proposed the new specific name *dacqueti* for the Indo-West Pacific species, honouring thereby burgomaster d'Acquet. In 1950, Sunier's views were confirmed (Holthuis 1950), except that it was pointed out that the name *Palaemon rosenbergii* De Man, 1879, for the Indo-West Pacific species is older than *P. dacqueti* Sunier, 1925, and that the specific name *rosenbergii* had to be used for the present species.

Not only on the specific level, but also on the generic, the nomenclature of the species has been rather muddled. When Weber (1795) established the new genus *Palaemon*, he placed in it three described species (and six invalid nomina nuda). These three species at present are assigned to the genera *Palaemon* and *Macrobrachium*. For the next half century, most authors used the name *Palaemon* in Weber's sense for both genera. Stimpson (1860) was the first to split *Palaemon*. He kept the name *Palaemon* for the species that at present are assigned to *Macrobrachium* and used the name

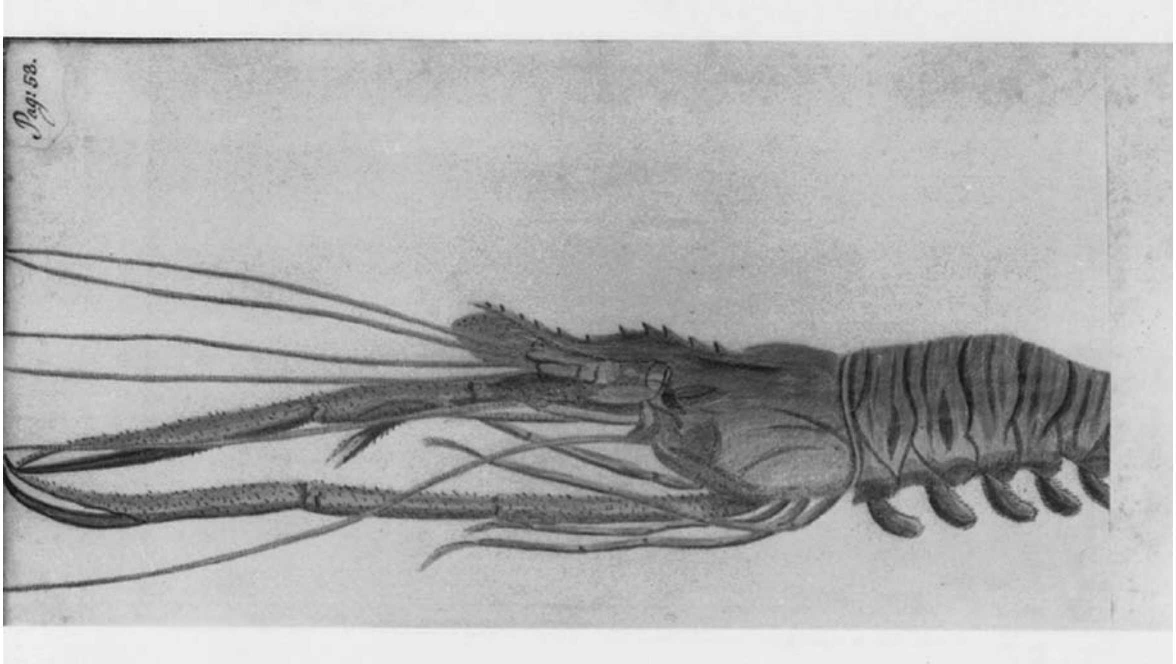

Fig. 2.1 Original figure of *Macrobrachium rosenbergii* (De Man) illustrated in Rumphius (1705). (Source: by courtesy of the Instituut voor de Tropen, Amsterdam.)

Leander for species now known as *Palaemon*. It was the American carcinologist Mary Jane Rathbun (1897), who first pointed out that the first valid type selection for the genus *Palaemon* was by Latreille (1810: 102, 422) who selected as the type species for that genus *Cancer squilla* Linnaeus, 1758, a species at present assigned to the genus *Palaemon*, but at that time usually indicated as *Leander squilla*. Rathbun then correctly pointed out that the genus that until then had usually been given the name *Leander* should be known as *Palaemon* Weber, 1795, and that what most zoologists at that time named *Palaemon* had to be called *Macrobrachium*. Rathbun's nomenclaturally perfectly correct statement was accepted by most American authors, but most of the European zoologists stuck to *Leander* and *Palaemon* as used by Stimpson (1860). The confusion caused by this usage of the name *Palaemon* in two different senses finally led to a request to the International Commission on Zoological Nomenclature for a decision in this matter, in order to restore the uniformity in the use of the various names. In 1959 the International Commission on Zoological Nomenclature (1959) issued on this case their Opinion 564, in which it was 'directed that the nominal genus *Palaemon* Weber, 1795, shall be cited as having as its type species the nominal species *Palaemon adspersus* Rathke, 1837'. *Palaemon adspersus* was the oldest available synonym of *Cancer squilla* Linnaeus, 1758, a species name that for other reasons had been suppressed by the Commission. This meant that Rathbun's views were now officially accepted. Since then, the name *Macrobrachium* has been universally used for the present genus. After having been known for about a century and a half as *Palaemon carcinus*, the species which forms the major topic of our book is now definitively known under the nomenclaturally correct name of *Macrobrachium rosenbergii*. It was only through the action of the International Commission that the undesirable nomenclatural confusion ended and uniformity and stability in the nomenclature of this important species was established.

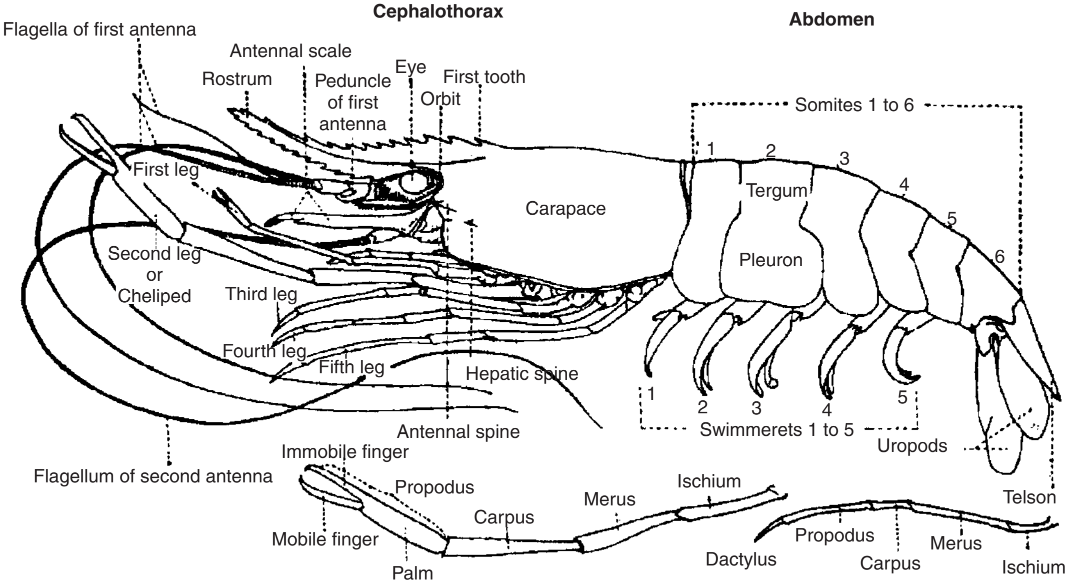

Fig. 2.2 Morphology of *Macrobrachium rosenbergii* (De Man). (Source: after Cowles, 1914.)

2.3 Taxonomy

2.3.1 The genus *Macrobrachium*

The genus is rather easily distinguished from allied genera. It can be characterised by the presence of a hepatic spine, absence of supraorbital and branchiostegal spines and a simple dactylus of the last three legs. The rostrum is well developed, compressed and toothed. The telson is provided with two pairs of dorsal and two pairs of posterior spines. Some authors synonymised *Macrobrachium* with *Cryphiops* Dana, 1852, the name of a South American genus. However, *Cryphiops* can immediately be distinguished from *Macrobrachium* by the fact that the hepatic spine of the carapace is absent. This spine is always present in *Macrobrachium* (except sometimes in abnormal specimens).

Efforts to sub-divide *Macrobrachium* into subgenera undertaken at the end of the 19th century, e.g. by Ortmann (1891), proved to be unsuccessful. Even though a few natural groups of species can be recognised within the genus, a complete subdivision proved impossible; perhaps such a subdivision can be realised when the genus and its species become better known.

2.3.2 The species *Macrobrachium rosenbergii* and nomenclature of its sub-species

Macrobrachium rosenbergii (Fig. 2.2) can be easily distinguished from other species of the genus by the combination of the following characteristics:

- it is the largest known of all *Macrobrachium* species (total body length up to 320 mm);
- it is characterised by the long rostrum with 11 to 14 dorsal teeth and (especially) by the 8 to 10 ventral teeth;
- the tip of the telson reaches distinctly beyond the posterior spines of the telson;
- the adult male has very long second chelipeds in which all segments are elongate and provided with blunt spines; and
- the movable finger of the second chelipeds of the adult male is covered by a dense velvet-like fur (except the extreme tip), while such fur is absent from the fixed finger and the rest of the cheliped.

Several zoologists recognise two sub-species within the species *M. rosenbergii*, an eastern and a western form. The range of the western form includes the east coast of India, the Bay of Bengal, the Gulf of Thailand, Malaysia, and western Indonesia (east to Borneo and Java); the eastern form inhabits the Philippines, eastern Indonesia namely Sulawesi (= Celebes) and Irian Jaya (= western New Guinea), and Papua New Guinea, in addition to North Australia. The exact limits of the two forms have not yet been definitely established, but the dividing line most probably runs west of the Philippines, continuing south between Borneo and Sulawesi, and ending between Java and the Lesser Sunda Islands. A study of more material, especially from the area between Borneo and New Guinea and between Java and Australia, is needed to establish whether the recognition of a sub-species is justified.

When De Man (1879) obtained a specimen from Andai, New Guinea, he thought its differences from the western form (which he indicated as *Palaemon carcinus*) so important, that he described it as a new species, *Palaemon rosenbergii*. Ortmann (1891) reduced the status of *M. rosenbergii* to that of a sub-species (or variety as he called it) and was followed in this by De Man himself (1892) and by the carcinologist Jean Roux in various papers dealing with New Guinea material. Most later authors did away with the sub-specific status and recognised just a single undivided species. It was Johnson (1973) who discussed the two forms again and made clear that he considered them sub-species of *Macrobrachium rosenbergii*. As the type locality of that species is Andai, New Guinea, the eastern form proved the typical form, *M. rosenbergii rosenbergii*. For the western form Johnson proposed the new name *Macrobrachium rosenbergii schenkeli*. Lindenfelser (1984), mostly on the basis of morphometric data, came to the same conclusion as Johnson, namely that two sub-species could be recognised in *M. rosenbergii*, but she did not bother with their nomenclature. Holthuis (1995) pointed out that if a western sub-species be recognised it should bear the name *Macrobrachium rosenbergii dacqueti* (Sunier, 1925), this being the oldest available name for that sub-species. Holthuis completely overlooked the existence of the sub-specific name *schenkeli* Johnson, 1958, but as that is a junior synonym of *dacqueti* Sunier, its existence does not change the validity of the latter sub-specific name.

In summary, it can be said that the present species is well established and well characterised; its valid name is *Macrobrachium rosenbergii* (De Man, 1879), and if sub-species be recognised, these should be known as *Macrobrachium rosenbergii rosenbergii* (De Man, 1879) for the eastern form, and *Macrobrachium rosenbergii dacqueti* (Sunier, 1925) for the western.

2.4 References

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3
Biology

Deborah Ismael and Michael B. New

Most of the information in this chapter is concerned with *Macrobrachium rosenbergii*. However, where specific information is lacking, other closely related crustaceans are used for illustrative purposes, it being reasonable to assume that their biology does not differ substantially. This chapter is not intended to be a complete treatise on decapod biology, merely a summary of those facets of *Macrobrachium* biology that are relevant to its aquaculture. For a more detailed account of decapod biology a most elegant recent publication about the American lobster (Factor 1995) may be consulted.

3.1 Habitat and life cycle

Macrobrachium rosenbergii lives in tropical freshwater environments that are influenced by adjacent brackishwater areas, due to the fact that its larval development must take place in brackishwater (Ling & Merican 1961; Sandifer *et al.* 1975). Some species of *Macrobrachium* prefer clearwater rivers while others, including *M. rosenbergii*, are often found in extremely turbid conditions (New & Singholka 1985). Gravid females migrate downstream into estuaries, where the eggs hatch as free-swimming larvae. From egg hatching until metamorphosis into postlarvae (PL), the planktonic larvae pass through several zoeal stages (Ling 1969; Uno & Kwon 1969). After metamorphosis PL assume a more benthic lifestyle and begin to migrate upstream towards freshwater (Fig. 3.1). According to Stephenson & Knight (1980, 1982) lower temperature may induce migrations of smaller PL, but the thermoregulatory behaviour of PL and juveniles indicates that the preferred temperature of both stages is 29–31°C (Díaz-Herrera & Bückle-Ramirez 1993).

While larvae are planktonic and actively swim tail first, with the ventral side uppermost, PL resemble miniature adult prawns and (apart from rapid evasive backwards propulsion) swim forwards, with the dorsal side uppermost (New & Singholka 1985). Postlarvae are also able to walk, not only on the substratum but also crawling over stones at the shallow edges of rivers and in rapids. They are also able to climb vertical surfaces (small waterfalls, weirs, etc.) and cross land, provided there is abundant moisture available. Adult prawns are active at night (Ling & Merican 1961; Ling 1969; Nakamura 1975), and during the day prawns rearrange their positions to remain in shaded areas (Karplus & Harpaz 1990). The juveniles exhibit nocturnal swimming activity, probably to take advantage of pelagic food resources, whereas during the day they settle on the bottom and crawl (Scudder *et al.* 1981).

The diet of larvae is principally zooplankton (mainly minute crustaceans), very small worms, and the larval stages of other crustaceans (New & Singholka 1985). Postlarval and adult *M. rosenbergii* are omnivorous, eating algae, aquatic plants, molluscs, aquatic insects, worms, and other crustaceans (Ling 1969). Cannibalistic behaviour may occur if food becomes insufficient, and/or in overpopulated ponds.

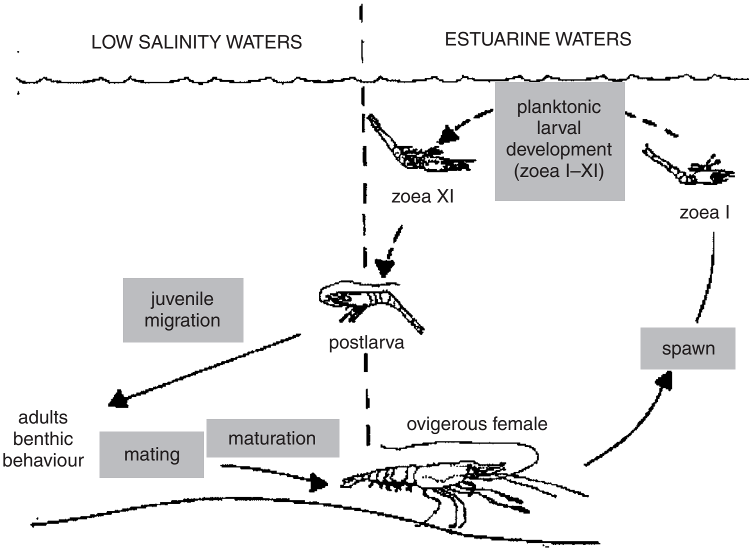

Fig. 3.1 Life cycle of *Macrobrachium rosenbergii*

3.2 Morphology and related topics

3.2.1 External morphology

3.2.1.1 Characteristics

Macrobrachium rosenbergii (De Man 1879) is the largest species of the genus: the males can reach a total length (from tip of rostrum to tip of telson) of 320 mm, the females of 250 mm. The body is usually of a greenish to brownish grey, sometimes more bluish colour, and is darker in larger specimens. There are irregular brown, grey and whitish streaks, often placed somewhat longitudinally. The lateral ridge of the rostrum may show a red colour. An orange spot is present on the articulations between the abdominal somites. The antennae are often blue. The chelipeds are also blue. All these colours are brighter in the smaller than in the very large specimens. Like all species of decapod shrimp and prawns, the body of this species consists of two distinct parts (see Fig. 2.2): the cephalothorax (usually named the 'head') and the abdomen (the 'tail'). The entire body is built up of 20 somites or body segments, 14 forming the cephalothorax, and 6 the abdomen. Each somite bears a pair of appendages; sometimes the appendages are reduced or completely absent.

The cephalothorax is formed by the fusion of the cephalon (six somites) and the thorax (eight somites). A large dorsal shield, the carapace, covers the cephalothorax completely dorsally and laterally. The carapace is smooth and hard, and it ends anterodorsally in the rostrum. The rostrum of this species is long, reaching beyond the antennal scale, except in very large specimens, where it may be slightly shorter. The rostrum is slender and somewhat sigmoid, with the distal part curved somewhat upward. Dorsally the rostrum bears 11 to 14 teeth (the first two of which are placed behind the orbit, while the others extend over the full length of the rostrum) and 8 to 10 below; this large number of ventral teeth distinguishes *M. rosenbergii* from practically all other species of the genus; also its length is quite characteristic. The rest of the carapace is smooth except for the presence of two spines on either side. The strong antennal spine is placed on the anterior margin of the carapace just below the lower limit of the orbit. The second spine, the hepatic spine, lies below the antennal and far behind the anterior carapace margin; a closed groove, the branchiostegal line, connects the hepatic spine with this anterior margin. The somites of the cephalon and thorax are completely fused and no segmentation is visible.

The cephalon has the following six appendages: 1, the eyes; 2, the first antennae or 'antennulae'; 3, the second antennae or 'antennae'; 4, the mandibles; 5, the first maxillae or 'maxillulae'; and 6, the second maxillae or 'maxillae'. The eyes are stalked and consist of a short sturdy peduncle which carries the rounded and darkly coloured cornea, in which are placed the ophthalmic elements that form the composite eye. The first antennae (also named antennulae) are formed of a three-segmented peduncle that at the top carries three flagella, used as tactile organs. The second antennae (named simply antennae when the term antennulae is used for the first) have a five-segmented peduncle that carries a long and strong single flagellum; on the outer margin of the third peduncular segment a large scale, the antennal scale or scaphocerite, is implanted. The mandibles and the first and second maxillae are placed near the mouth opening and are termed mouthparts; they play a role in the ingestion of food. The mandibles are short heavily calcified molar-like jaws and serve for grinding up the hard parts in the food; the first and second maxillae are thin and lamelliform. These mouthparts are small and are entirely covered by the following appendages.

Of the eight pairs of appendages of the thorax the first three, named maxillipeds I, II and III, can also be termed mouthparts; maxillipeds I and II are lamelliform like the maxillae, while maxilliped III is pediform, and sometimes may be mistaken for a pereiopod. The following five legs are the pereiopods or true legs. The first two of these carry chelae or pincers and are termed chelipeds. The last three pairs end in a simple claw and are named walking legs. The first cheliped is narrow and slender, it is smooth and of about the same width throughout; it is distinctly shorter and thinner than the second cheliped which is the largest of all legs. The second cheliped is strong, bears numerous spinules and is far more robust than any other leg; the left and right second leg are very similar in shape and size. In the adult males this leg becomes excessively long and may reach with a large part of the merus (plus carpus and chela) beyond the antennal scale. In females and younger males it surpasses the scale with only part of the carpus. In both sexes the segments of this leg are slender. The carpus is always longer than the merus. Numerous spinules are present on all segments; in the large males the carpus and merus have especially large and strong spinules. The fingers of the chelae are slightly shorter than the palm, and each ends in a sharp inward tip. A characteristic of the species is the fact that the mobile finger is covered with a dense, though rather short pubescence, which leaves only the very distal part of the finger naked; no such pubescence is found on the fixed finger or any other part of the cheliped. The following three pairs of legs are rather similar, they have no pincers, are slender and in either sex are much shorter than the second cheliped.

In contrast to the cephalothorax, the segmentation of the abdomen is very distinct. This part of the body consists of six somites, each of which bears a pair of ventral appendages, called pleopods or swimmerets, which consist of a peduncle (protopod), with two supple lamelliform blades. As the name indicates, these swimmerets are used for swimming, like the walking legs are used for movement on the ground. The swimmerets of the sixth abdominal somite are stiff and hard and, with the telson, serve as a tail fan. The telson is a median appendage on the posterior margin of the sixth abdominal somite. It is elongate triangular and has two pairs of dorsal spinules; its posterior margin is produced in the middle into a strong broad point, which reaches distinctly beyond the two pairs of spinules that are implanted on the posterior margin; in most other species of *Macrobrachium* this point is overreached by the spinules. The tail fan is used in making a sudden forward movement, with which the animal can propel itself in a backward direction. The female, when 'berried' carries the small and very numerous eggs under the abdomen, where they are attached to the swimmerets.

3.2.1.2 Function of external structures

While external morphology has been fully described in section 3.2.1.1, some brief comments on the function of the various structures, based on the work of McLaughlin (1980, 1982), Cavalcanti *et al.* (1986) and Kaestner (1993), are appropriate here.

In spite of several chemo- and mechanoreceptors identified on the chelae, ambulatory legs and mandibles of a number of crustacea, the antennules and antennae are considered the most important sites of sensory reception. The statocyst (gravity receptor) is localised in the basal segment of the antennular peduncle. The chemoreceptor cells in the pereiopods of *M. rosenbergii* have, on average, broader response spectra than the chemoreceptor cells in the antennules and pereiopods of lobsters. They are sensitive not only to aqueous extracts of food but also to salts. Such sensitivity might be involved with the reproductive behaviour of this species, since gravid females move into estuaries, where their eggs hatch. The detection of salts might be also important for the migration of juveniles into adult habitats (Derby & Harpaz 1988).

Three sets of appendages are concerned with feeding: the mandibles, maxillules and maxillae. The mandibles, being well developed with incisor and molar processes and a three-segmented palp, are specialised for cutting and crunching. The first and second maxillae are flat, thin and lamelliform. Each of the first maxillae (maxillulae), which are involved with food handling, consists of an endopod, which is bilobed at the top, and two endites. The exopod of each second maxillae is developed as a scaphognathite whose constant beating produces a water current in the gill chamber, promoting respiratory gas exchange. The second maxillae also include an endopod and two endites; as in the case of the first maxillae these assist in the handling of the food towards the mandibles. The first maxillae (maxillulae), which are entirely covered by the second maxillae, are unlikely to have any role in the movement of water over the gills.

The first three thoracic appendages (maxillipeds), which are located between the mouth appendages and the locomotor appendages, are utilised for feeding or food handling. The other five thoracic appendages (pereiopods) are well-developed appendages, consisting of seven segments: coxa, basis, ischium, merus, carpus, propodus (propus) and dactylus. The first pair are much smaller than the second pereiopods; they are chelate and are utilised in capturing food. The second pair are chelate and are involved with several functions in addition to food capture, including agonistic and mating behaviour. Due to the presence of true chelae, the fourth and fifth thoracic appendages are often referred to as chelipeds. The final three thoracic appendages (pereiopods six to eight) are typical walking legs.

The first five of the six abdominal appendages consist of pairs of well-developed supple natatory appendages (pleopods). These five pleopods have biramous structures, adapted for swimming. In females, these are developed with attachment sites for egg clusters. In males, the second pair of pleopods are modified for copulation (Fig. 3.2). As noted in section 3.2.1.1, the sixth somite bears the rigid uropods which, together with the telson, form a very effective propulsive structure (tail fan) for reverse movement.

A number of important morphological characteristics differentiate caridean prawns from penaeid shrimp (Fig. 3.3). In all carideans the second abdominal pleura overlap both first and

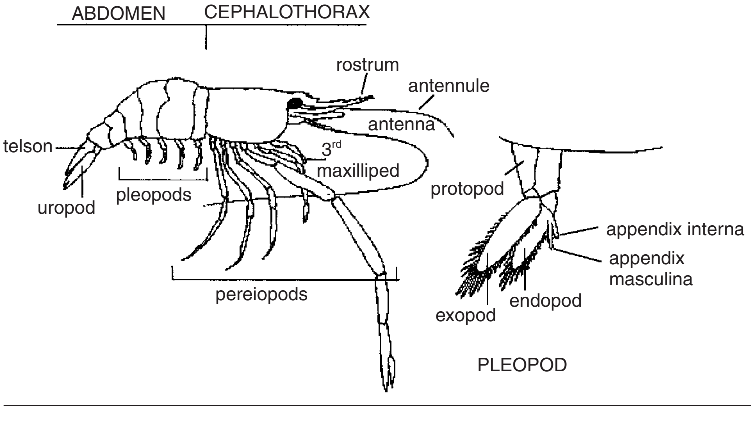

Fig. 3.2 Male external morphology of *Macrobrachium rosenbergii* and details of second pleopod. (Source: modified from Pinheiro & Hebling, 1998.)

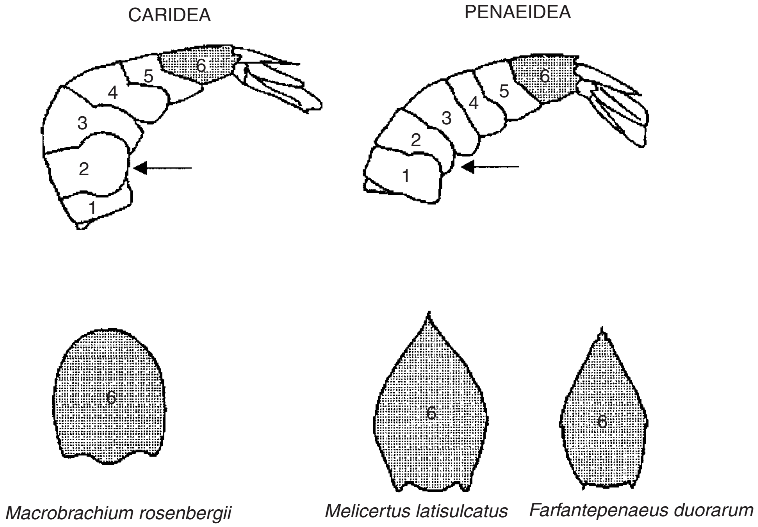
CARIDEA
PENAEIDEA
1
2
3
4
5
6
1
2
3
4
5
6
6
6
6
Macrobrachium rosenbergii
Melicertus latisulcatus
Farfantepenaeus duorarum

Fig. 3.3 Distinguishing features of carideans and penaeids. Note: *Melicertus latisulcatus* was formerly known as *Penaeus latisulcatus*; *Farfantepenaeus duorarum* was formerly known as *Penaeus duorarum*. (Source: after Fincham & Wickins, 1976.)

third pleura, and the terminal chelae on the third pereiopods are lacking (McLaughlin 1980). An additional distinguishing feature is that most carideans, including *Macrobrachium* spp., have a smooth, rounded dorsal abdominal surface, while most penaeids have a simple or complex ridge at the dorsal apex of the abdomen (Fincham & Wickins 1976).

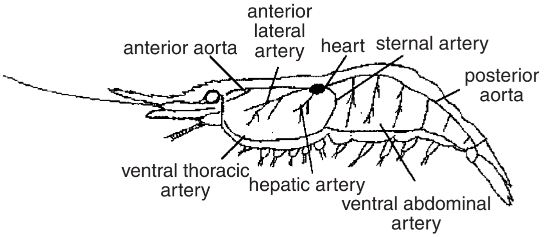

Fig. 3.4 The circulatory system of caridean prawns

3.2.2 Internal morphology

This section is concerned principally with morphology, but necessarily and briefly discusses some important and related physiological aspects, for which further reading is referenced.

3.2.2.1 Circulatory system

Decapod circulatory systems have been described by McLaughlin (1983), Bliss (1990) and McMahon & Burnett (1990), on whose work this section is based.

The decapod heart is a condensed muscular structure (ventricule), which has paired ostial valves (normally three) in its wall that communicate between the ventricular cavities and the surrounding areas, known as the pericardium (or pericardial sinus). The heart pumps haemolymph into a complex arterial system which perfuses the tissues. The arterial system comprises several distinct outflow systems: a single anterior aorta that provides blood to the eyes and supra-oesophageal ganglion; anterior lateral arteries that are the primary suppliers of blood to the cephalic appendages, foregut walls, musculature, antennal glands and carapace; hepatic arteries, leaving anterolaterally; a sternal artery that runs toward the ventral region and divides into anterior ventral thoracic arteries and posterior ventral abdominal arteries (Fig. 3.4). Venous return occurs via distinct channels into the collecting sinuses that supply the gills and branchiostegal circulations, and then to the pericardial cavity and finally to the heart. As a result of this arrangement the heart is directly supplied with oxygenated blood from the gills, which is pumped to the tissues.

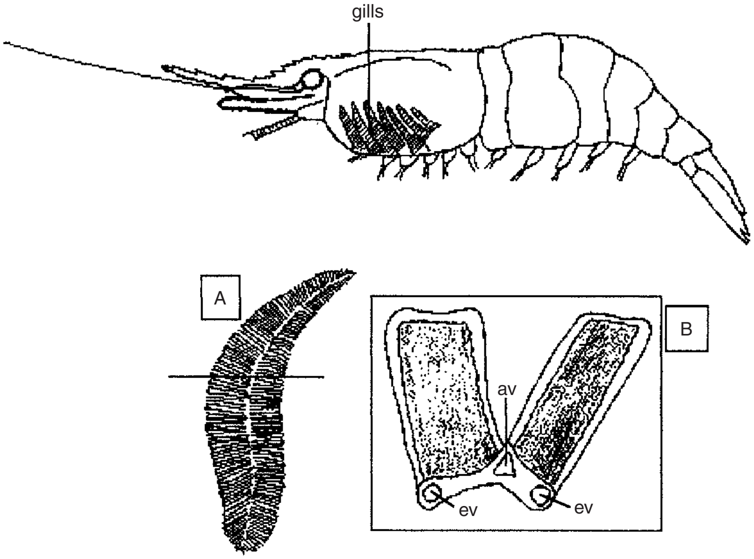

Fig. 3.5 General anatomy of the gills of *Macrobrachium olfersii*. (Source: after McNamara & Lima, 1997.)

Key: A = general anatomy of the gill; B = general anatomy of a gill lamella; ev = lateral efferent vessels; av = central afferent vessel.

McMahon & Burnett (1990) reviewed the physiology of several advanced crustacean open circulatory systems, suggesting that they are not poorly designed structures with sluggish performance, as is commonly assumed. These systems are, in fact, complex, very efficient and highly regulated.

3.2.2.2 Respiratory system

The gill structure of *Macrobrachium olfersii* has been described in detail by Freire & McNamara (1995), and may be representative of other *Macrobrachium* spp. The gills are phyllobranchiate, i.e. there is an elongated axial structure with a series of lateral branches (respiratory lamellae). Each gill (Fig. 3.5) bears a very large number of lamellae that consist of flattened plates, in which the perfusing haemolymph flows from lateral efferent vessels to the outer marginal canals, across the haemilamella by means of gill capillaries to the inner marginal canals and back through the central afferent vessel.

The gills are enclosed in branchial chambers (Fig. 3.5), which are formed between the thoracic body wall and the inner surface of the carapace (branchiostegite). These chambers offer protection to the gills, as well as directing the water current over them. The beating of a leaf-like flap, the scaphognathite (the exopod of the maxillae), causes a current of water to enter into the branchial chamber. Water is drawn from openings between the bases of the pereiopods and the thoracic walls, flows through the gills within the branchial chambers and is expelled anteriorly. The gills are directly involved in the respiratory process, as well as in the osmo-ionic regulation and excretion.

Oxygen uptake and its transport to tissues are facilitated by respiratory pigments, which in *M. rosenbergii* is haemocyanin, a copper-containing protein, as reported in several other decapods. According to Taylor & Funge-Smith (1994), the oxygen affinity of haemocyanin of *M. rosenbergii* is sensitive to changes in temperature, and also in salinity to a lesser extent. These phenomena are of great importance, since this animal is exposed to large fluctuations in environmental parameters, especially as it migrates to estuaries for spawning. Until now, there is no information on whether adaptive changes of the properties of haemocyanin may occur during ontogenesis.

3.2.2.3 Digestive system

The alimentary canal of decapods is a tubular structure, which begins with an anteroventral mouth, runs dorsally along the body and terminates in the anus, located in the base of the telson. The digestive system is divided into three distinct regions (foregut, midgut and hindgut) and includes the digestive gland, cecae and diverticulae. The foregut and hindgut are ectodermal in origin whereas the midgut is endodermal and lacks a cuticular covering; thus its cells are directly contacted with the lumen (Icely & Nott 1992).

The foregut is a chambered structure situated in the cephalothorax and consists of the oesophagus and stomach (cardiac and pyloric chambers). These regions are provided with trituration and filtering mechanisms which, together with enzymes, initiate the digestive process. The gastric mill, a grinding mechanism formed by ossicles in the anterior chamber of the foregut, is present in all decapods except in some Caridea (e.g. *M. rosenbergii*). Thus, mastication in *M. rosenbergii* depends on the mandibles. Food particles are broken down, separated and then transferred into the midgut (Icely & Nott 1992). Kihara (1997) investigated the morphology of the foregut in juveniles of *M. rosenbergii*, and described the following characteristics: a tubular oesophagus characterised by folds and grooves, opening into the cardiac chamber. This exhibits an external surface with an overall rugose appearance with an absence of ossicles. Its internal wall has longitudinal folds, covered with setae. Cardio-pyloric valves regulate the passage of food through the cardiac and pyloric chambers which are divided into a compaction zone and gland filters. Pyloric-intestinal and pyloric-hepatopancreatic valves occur at the fore-midgut junction.

The midgut of decapods is the primary site of enzyme action and nutrient absorption (Dall & Moriarty 1983). It exhibits a well-developed glandular appendage, known as the hepatopancreas (or digestive gland), forming a compact complex of ducts and blind-ending tubules, which occupy a large part of the cephalothorax. This glandular appendage is involved with the synthesis and secretion of digestive enzymes, the re-absorption of nutrients, the storage of energy reserves, as well as ion transport for mono- and di-valent cations and anions (Dall & Moriarty 1983; Icely & Nott 1992). A sodium-dependent glucose transport mechanism in the midgut epithelium of *M. rosenbergii* was demonstrated by Ahearn & Maginniss (1977). The indigestible material is packaged into faecal pellets within the midgut and pushed by peristaltic contractions into the hindgut. This final region is relatively short and terminates in a muscular controlled anus.

3.2.2.4 Excretory system

The excretory system of decapods has been described by McLaughlin (1983), and Mantel & Farmer (1983), on whose work this section has been based.

Several tissues and organs participate in the excretion of metabolic wastes in crustaceans, but the primary organ of urine production in adult malacostracans is the antennal gland (or green gland), which is paired and located in the cephalothorax. The morphology of this gland follows a basic plan: each consists of an initial sack (coelomosac), a long excretory tubule (a labyrinth, and a nephridial canal), and a large bladder. The opening is an excretory pore near the base of the antennae (hence the name, antennal gland).

Urine is formed in the antennal gland by filtration and re-absorption, with tubular secretion added. The most studied antennal gland is that of crayfish (Mantel & Farmer 1983). The distal portion of its labyrinth contains cells with active endocytotic vesicles, which may absorb proteins. The bladder is the site of uptake and secretion of ions and water. Glucose re-absorption also occurs in the antennal gland, but the specific site of this process has not been identified. In freshwater hyper-regulators the renal organ is effective in salt re-absorption, producing a dilute urine.

Sarver *et al.* (1994) hypothesised that only a portion of the crawfish antennal gland Na^+/K^+-ATPase is involved with renal salt re-absorption, with the consequential production of dilute urine. The other portion may power non-osmoregulatory transport functions, such as organic acid secretion into the urine, and sugar and amino acid re-absorption from it.

Although the antennal gland is denominated as the excretory organ, the site of nitrogenous waste excretion is actually the gills. In decapods, the end product of protein metabolism is mainly excreted as ammonia, with small amounts as amino acids, urea and uric acid (Regnault 1987). According to Chen & Kou (1996a), *M. rosenbergii* was found to excrete 70.2% of its total nitrogen at 32°C as ammonia-N, 25.6% as organic-N (mainly amino acids) and 4.2% as urea-N.

The effects of environmental (temperature, salinity and pH), and physiological (moult cycle) factors on nitrogen excretion have been described for *M. rosenbergii* (Armstrong *et al.* 1981; Stern & Cohen 1982; Stern *et al.* 1984; Chen & Kou 1996a,b; Schmitt & Uglow 1996).

3.2.2.5 Reproductive system

The internal reproductive structures of *M. rosenbergii* are located in the cephalothorax.

In males, they consist primarily of pairs of testes, which are fused and lie mid-dorsally in the cephalothorax, giving rise to the vas deferens. The paired vasa deferentia are simple tubes that end in terminal ampullae, which contain the spermatophores and open at the gonopores on the coxae of the fifth pereiopods (Fig. 3.6). During mating, the ampullae extrude the spermatophores, containing the sperm mass (Sandifer & Smith 1985). Besides these structures, an androgenic gland is attached to the vasa deferentia; this is involved with the development and regeneration of secondary male sexual characteristics (Nagamine *et al.* 1980) and also controls morphotypic differentiation (Sagi *et al.* 1990).

In females, the paired ovaries are located dorsally to the stomach and hepatopancreas. They give rise to a pair of oviducts which extend towards, and open into, the gonopores on the basal segment of the third pereopods (Fig. 3.6) (Sandifer & Smith 1985).

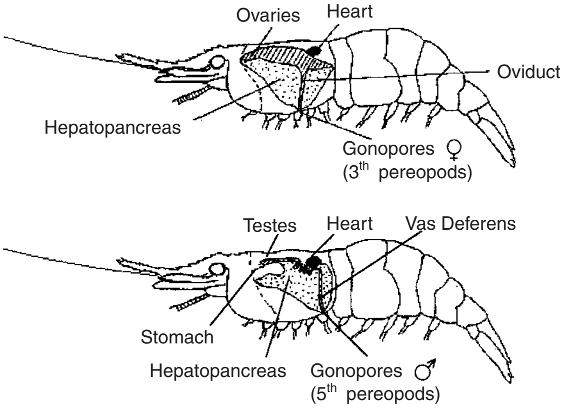

Fig. 3.6 The internal reproductive organs of *Macrobrachium rosenbergii*. (Source: modified after Sandifer & Smith, 1985.)

3.2.2.6 Nervous system

The crustacean nervous system consists of a large supra-oesophageal ganglionic mass (also referred to as the brain) and a ventral nerve cord with a pair of ganglia corresponding to each embryonic somite. The ganglia are joined longitudinally by connectives and transversely by commissures (Fig. 3.7a) (McLaughlin 1983).

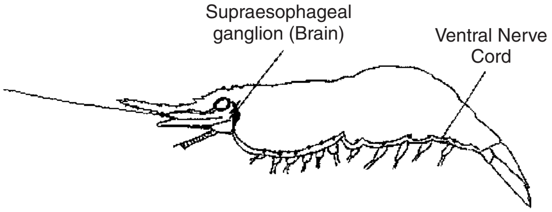

Fig. 3.7a Diagram of the nervous system of caridean prawns

The crustacean brain consists of three areas (Sandeman *et al.* 1993). Firstly, there is the protocerebrum, which can be divided into the optic ganglia, which innervates the compound retina, and the lateral and medial protocerebrum. These areas also innervate the frontal organs, sinus gland and muscles of the head. Secondly, there is the deutocerebrum, which contains the neuropils associated with the antennules. The olfactory lobes receive the total input from the chemoreceptors on the antennules, and also contain the motorneurons that control their movements. Finally, there is the tritocerebrum, which contains the tegumentary neuropil that receives the nerve fibres from sensory cells from the carapace and the neuropils that receive the inputs from the antennae motor- and mechanoreceptors.

In the ventral nerve cord, the first ganglion (suboesophageal) and the remaining ganglia (from the thorax and abdomen) receive inputs from the sensory cells dispersed in the body and supply nerves to the muscles of the mouth parts, pereiopods, pleopods and tail fan. In addition, the stomatogastric ganglia supply nerves to the oesophagus and the foregut (Bliss 1990).

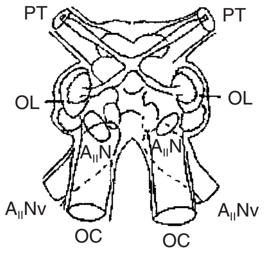

Fig. 3.7b Diagram of the brain of *Macrobrachium novaehollandiae*. (Source: modified from Sandeman *et al.*, 1993.)

Key: PT = protocerebral tract; OC = oesophageal connective; OL = olfactory lobe; $A_{II}N$ = antenna II neuropils; $A_{II}Nv$ = antenna II nerve root.

Sandeman *et al.* (1993) surveyed the morphology of several decapod crustacean brains. They described the anatomy of the brain of *M. novaehollandiae*, which may be representative for other carideans. It exhibits well-developed olfactory and antenna neuropils. The antennular neuropils are smaller and subdivided. The olfactory lobes are linked to neuropils in the eyestalks by a large tract (Fig. 3.7b).

Another structure associated with the anterior part of the brain, is the organ of Bellonci, which in *M. rosenbergii* is located in the haemocoel in the distal part of the eyestalk (Hallberg & Kauri 1992). The membrane of the sensory cells of this organ has other characteristics besides the photosensitive membranes of the compound eyes, indicating that it might function in some other sensory mode.

3.3 Reproduction

3.3.1 Sexual dimorphism

According to Nagamine & Knight (1980), *M. rosenbergii* can be sexually distinguished with the first appearance of gonopores in juveniles, at 5.9 mm (carapace length) for males and 7.6 mm for females. Male gonopores are situated at the base of the coxae of the fifth pereiopods and are covered by flaps, while female gonopores appear as oval apertures on the coxae of the third pereiopods and are covered with a membrane. New & Singholka (1985) illustrated the fact that the ventral side of the first abdominal somite in male *M. rosenbergii* has a central lump or point, which can be felt with the finger. This feature is absent in females.

Mature females (Plate 2, facing p. 220) have proportionally smaller heads and claws than males (Sandifer & Smith 1985). They exhibit a typical brood chamber, formed by the first, second and third abdominal pleurae; this characteristic does not exist in penaeid shrimp, as they never carry their eggs, but spawn them free in the water. *Macrobrachium* also exhibit reproductive setae on the pleopods and thorax, which are functionally distinct: the ovipositing setae, which are mostly permanent, on the coxae of the last three pairs of pereiopods and pleopods guide the eggs during spawning, and the ovigerous setae, which only occur following a pre-spawning moult and are used to secure the eggs to the pleopods for brooding (Nagamine & Knight 1980). According to New & Singholka (1985), female *M. rosenbergii* can lay between 80 000 and 100 000 eggs in each spawning when fully mature. However, their first broods are often not more than 5000–20 000. Ovaries frequently ripen again while eggs are being carried in the brood chamber. Sureshkumar & Kurup (1998) found that fecundity was strongly correlated with total weight, total length, and carapace length. The average weight of the large females studied by these authors ($n = 80$) was 109.9 g and the average number of eggs was 95 687.

Male prawns, except small males (SM), are easily recognised by longer and stronger chelipeds with larger spines than the females. Apart from these characteristics, and the presence of gonopores, males may also be recognised by the appendix masculina, a spinous process adjacent to the appendix interna on the endopod of the second pleopod (Sandifer & Smith 1985), as illustrated in Fig. 3.2.

Sexually mature populations of *M. rosenbergii* are composed of three distinct male morphotypes: blue claw (BC) males are relatively large and possess long blue claws, covered with spines, with high claw to body length ratio. Orange claw (OC) males possess medium-sized, spineless and often orange-coloured claws, with lower claw to body length ratio. Small males (SM) possess short delicate claws, often with little pigment and translucent, with the lowest claw to body length ratio (Kuris *et al.* 1987). The characteristics of the various male morphotypes, and their impact on the management of grow-out systems for *M. rosenbergii*, are fully discussed and illustrated in Chapter 16.

Sexual differentiation in decapods is controlled by the presence of the androgenic hormone, which induces the male characteristics of the genital tract. The development of the androgenic gland depends directly on male genotype (Charniaux-Cotton & Payen 1985). The ovarian differentiation of the gonadal rudiment takes place spontaneously in the absence of the androgenic hormone (Nagamine *et al.* 1980).

3.3.2 Mating and spawning

Freshwater prawns can reproduce either continuously or periodically, depending on their distribution. In temperate regions, prawn reproduction coincides with summer, while in tropical regions it is related to the onset of the rainy season (Valenti 1984).

Mating behaviour has been discussed by several authors, including Ling (1969), Sandifer & Smith (1985), and Valenti (1985, 1987). After ovarian maturation, *M. rosenbergii* females experience a moult, known as a pre-spawning or pre-mating moult, which usually occurs at night. After this moulting process occurs, courting and mating commence. Courting behaviour involves stroking, movements of the antennae and male chelipeds touching the female, and raising the body, which lasts a few minutes until the female accepts the male. Mating is preceded by a cleaning act, in which the male holds the female and carefully cleans her ventral thoracic region. Following this behaviour, copulation begins; the male inserting a sperm mass into the pre-cleaned area of the female. The reproductive behaviour of freshwater prawns is also discussed in Chapter 16.

Recent work (Thomas 1998; R. Smullen, pers. comm. 1999) has identified six distinct stages in mating behaviour. Previously, very little work had been conducted on female mating behaviour but these studies outline the characteristic mating response of a pre-copulatory Drach stage A (see p. 30) moulted female. The six stages described are:

(1) The female approaches a BC male.
(2) The female climbs over the telson of the male. Antennal contact is maintained at all times by sweeping movements between male and female at this stage.
(3) The female orientates herself to the front of the male and moves backwards until she is between his chelae.
(4) Once between his chelae, the female may turn to face the male, making contact with the male's walking legs. Prior to fertilisation, the female re-orientates herself in order to position her dorsal telson under his head region.
(5) The male mounts the female, and begins characteristic rubbing action with pleopods on the ventral lower cephalothorax and upper abdominal segments of the female. The female appears to become torpid.
(6) The male grasps the female's rostrum with his chelate pereiopods, and may also grasp the gill operculum. The female is turned ventral side up with chelae stretched out in front, and remains torpid. This ensures that the reproductive organs are aligned.

Once mating has occurred, the male moves off the female, who recovers and reverts to normal behaviour. The fact that the female is rotated in this manner may be the reason why the female chooses the largest BC male. In this position she is vulnerable, and the BC male will defend her aggressively from other males. The rubbing and cleaning behaviour may play a role in creating the trance-like torpor observed in the female. According to R. Smullen (pers. comm. 1999) it has been demonstrated in *Panulirus cygnus* in Western Australia, that scratching the region between the cephalothorax and the abdomen results in the crayfish becoming torpid. In this state, it can be positioned ventral side up for between 2 and 3 min. However, when placed in its normal position, the crayfish reverts to normal behaviour. It is possible that the similar action by the male *Macrobrachium*, which is described above, induces torpor in the female. However, this needs further investigation, as it is quite possible that this behaviour may be an attempt by the male to remove the spermatophore of a previous partner.

It had been previously believed that male *M. rosenbergii* are attracted to females when their ovaries are in a late maturing stage. Recent studies (Thomas 1998; R. Smullen, pers. comm. 1999) demonstrated that this is not the case. Newly moulted stage IV females (Drach stage A) are very strongly attracted to BC males. Under experimentation, when BC males are enclosed in a perforated box, the attraction time of a female to a BC male is totally dependent on ovarian stage, with the stage described above demonstrating the most rapid pairing. Attraction time decreases in descending order from premoult ovarian stages IV to I, the latter being attracted least to the BC males. Furthermore, females at any ovarian stage are not attracted to either OC males or SM. When the attraction experiments were reversed, i.e. males were free to move and could approach enclosed females, only the SM were attracted to the females, again with attraction times corresponding to the ovarian stages, i.e. soft postmoult females were the most strongly attractive to the SM. This would correspond to the normal observed behaviour of the SM, which attempts sneak copulation with females that are guarded as part of a BC harem. This study also demonstrated fighting behaviour between BC males in the presence of soft mature females. If females of differing ovarian stages were placed in an opaque perforated box, the BC males would fight only in the presence of a late stage IV female or a newly moulted mature female. This topic needs further investigation because the BC males could be separated into two categories: some fight all the time, while others fight only in the presence of females. These studies indicated that pheromones play a major role in attraction, both between the sexes and the different morphotypes. Further work on this subject is clearly necessary, since the identification of male and female pheromones could play a major role in improving the aquaculture and husbandry of this species.

Macrobrachium rosenbergii, like other decapods, has aflagellate and non-motile spermatozoa (Felgenhauer & Abele 1991), which are enclosed in packets called spermatophores formed by a secretion of the male accessory sex glands. These are rich in glycoprotein and acid mucopolysaccharides (Dougherty *et al.* 1986), which may keep the delicate spermatozoa viable until fertilisation (Subramoniam 1991). Within a few hours after copulation, spawning is initiated through the gonopores into the brood chamber, guided by the ovipositing setae; hence fertilisation occurs externally. The eggs remain adhered to the female ovigerous setae during the whole embryonic development, which lasts around 3 weeks (depending on temperature). Finally, hatching occurs and the embryos hatch into free-swimming zoeae. In contrast, penaeid shrimps, once spawned and fertilised, release their eggs into the environment where they hatch. The embryonic development of penaeids is shorter than carideans, and the eggs hatch into nauplii.

At spawning, the eggs of *M. rosenbergii* have low water (55%) and ash (0.9% DW [dry weight]) contents, and the remainder is a protein-rich yolk (31.1 μg protein and 14.4 μg lipid); together, the protein and lipid contents occupy virtually all of the organic content of the egg (Clarke *et al.* 1990). According to these authors, both lipids and proteins are utilised in the developmental processes, but the former provide the greater proportion of energy (0.21 J from lipids as compared to 0.12 J from protein, between the fifth day of development and the last day before hatching). During this period the developing embryo utilises 4.8 μg protein and 5.3 μg lipid. After hatching, the first zoeal stage larvae have enough energy to go through their first moult without feeding.

3.3.3 Physiology

Endocrine control of reproduction in crustaceans is a very complex process which has been extensively reviewed by Adiyodi & Adiyodi (1974), Adiyodi (1985), and Fingerman (1987), whose studies are summarised below.

The X organ-sinus gland (XOSG) complex, located in the eyestalks, contains two distinct hormones that inhibit moulting (MIH) and gonadal development (GIH). Another neurohormone, found in the brain and thoracic ganglia, is the gonad-stimulating hormone (GSH). When MIH and GSH levels in the haemolymph are low, and the levels of GIH and the moult hormone (MH) secreted by the Y organs are high, moulting is induced. Low titres of GIH start the vitellogenic and spermatogenic processes.

The ganglionic XOSG complex is the major site of neuroendocrine control in crustaceans, and is involved with several physiological processes, such as moulting, growth, sexual maturation and the regulation of metabolism (Adiyodi 1985). The nerve fibres from the ganglionic X organ run to the sinus gland, a neurohaemal organ that stores and

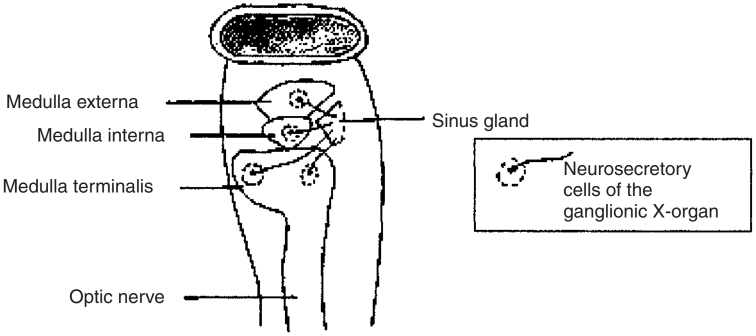

Fig. 3.8 Internal eyestalk structures in *Macrobrachium acanthurus*. (Source: adapted from Corrêa *et al.*, 1996b.)

releases the neurohormones. The ganglionic X organ morphology and the neurosecretory system of freshwater prawns were investigated by Corrêa *et al.* (1996b). According to these authors, the eyestalk of *M. acanthurus* follows the typical standard found in the majority of the decapods, i.e. the nervous tissue is concentrated into three lobes: the most proximal is the medulla terminalis (a brain centre) that is connected with the protocerebrum by the optic lobe peduncle (Fig. 3.8). The other two lobes, the medulla interna and externa, are optic centres. The medulla externa is connected with the lamina ganglionaris, the neuropil lying immediately behind the retina. Eight cellular groups were identified around the neuropil of the medulla externa, interna and terminalis. Corrêa *et al.* (1996a) identified five different types of neurosecretory terminal axons in the neurohaemal organ, the sinus gland, of *M. acanthurus*. They suggested that the neurosecretory granules might be released mainly by exocytosis.

The ovarian development of *M. rosenbergii* can be classified into five stages, based on their size and colour, which can be observed through the carapace (Chang & Shih 1995). Such stages reflect vitellogenesis, i.e. egg yolk production and accumulation. In stage I, the ovaries are white, corresponding to pre-vitellogenesis; in stage II a small yellow mass of ovarian tissue can be observed dorsally in the carapace, near the epigastric tooth, consisting of pre- and vitellogenic oocytes; in stages III–IV, the ovaries are orange, corresponding to vitellogenesis; and stage V is characterised by reddish ovaries, extending from behind the eyes up to the first abdominal segment. At this time, the ovaries are composed of yolk globules fully occupying the oocytes. After the ovaries reach stage V, the females are ready to moult and spawn. The description of the ovarian stages of *M. rosenbergii* is similar to that described for *M. acanthurus* by Carvalho & Pereira (1981).

Sagi *et al.* (1995) suggested that an extra-ovarian source of vitellogenin existed in *M. rosenbergii*. Oogenesis occurs continuously, the ovary redeveloping even when the females are 'berried'. Induction of spawning, in order to achieve the synchrony which would be beneficial in hatcheries, has been achieved by Zhao *et al.* (1995). These workers dropped 40 µl of 1% juvenile hormone analogue-ZR515 on each prawn body surface. The hormone permeated through the integument to stimulate maturation and spawning. After 16–17 days, the spawning rate reached 41.8%, which was over 50% higher than routine. Large amounts of high polarity immunoreactive products (HPP) accumulate in the ovaries and eggs of *M. rosenbergii* during vitellogenesis and embryogenesis (Wilder & Aida 1995). These workers also found that methyl farnesoate (MF) was present but, although its level fluctuated during the moult cycle (Wilder *et al.* 1995), whether it is involved in reproduction is as yet unclear. This topic has been reviewed by Wilder (1998).

Like moulting, the reproductive processes require significant energy mobilisation. Sensory neurons send information to the endocrine systems in the form of neurosecretory hormones. The XOSG complex plays a central role in the regulation of metabolism. The hyperglycaemic hormone (HGH), more recently referred to as the crustacean hyperglycaemic hormone (CHH) (Chang 1992), is synthesised and released from the XOSG and is primarily concerned with carbohydrate metabolism. Lin *et al*. (1998) showed that an injection of XOSG extract evoked a hyperglycaemic response which peaked in 1 hour. Hyperglycaemia is a characteristic response to cold shock in *M. rosenbergii* but CHH may not be the only factor (Kuo & Yang 1999); norepinephrine and/or octapamine may also be involved.

3.4 Ecdysis and growth

Crustaceans periodically shed their old exoskeleton, resulting in somatic tissue growth. This process, known as moulting (or ecdysis), is a consequence of cyclic and continuous morpho-physiological events. During the moulting cycle the animals increase their size by means of water absorption. However, somatic growth occurs during the intermoult period. In this phase, a slight increase in animal external dimensions may occur due to the flexibility of the membranes which connect with the exoskeleton (Mauchline 1977; Hartnoll 1982).

Generally, *Macrobrachium* males grow larger than females (Holthuis 1980), except for *M. ohione* (Truesdale & Mermilliod 1979). Bertalanffy mathematical models have been used to describe the growth rate of several species (Guest 1979; Bond & Buckup 1983; Valenti *et al.* 1987, 1994; Kurup *et al.* 1992). These equations suggest that the life span of small species (e.g. *M. borelli* and *M. acanthurus*) is about 2 years. *Macrobrachium rosenbergii* can reach at least 3 years old, while in *M. carcinus* the life span varies from 6 to 8 years.

Kurup *et al.* (1992) observed that *M. rosenbergii* males and females can reach 330 and 290 mm, respectively, somewhat larger than observed by Holthuis (see section 3.2.1.1). Generally, female growth in decapod crustaceans is retarded after they reach maturity, due to the fact that part of their energy is diverted to egg production and incubation (Hartnoll 1982). According to Ra'anan *et al.* (1991) the growth rate of immature females is relatively high, initially exponential, but after sexual maturation this rate reduces considerably. Thus, size variation decreases with time, an initial highly variable female size distribution being replaced by a relatively normal distribution, with a mean value above the size threshold (about 18–26 g) for maturation. Male growth exhibits a very complex model which is fully discussed in Chapter 16. Growth rate and its consequences for *M. rosenbergii* production in ponds is discussed in Chapter 10.

The decapod moult cycle can be divided into stages and substages, which have been classified by Drach (1939) and Drach & Tchernigovtzeff (1967). A moult cycle staging technique for rapid identification in live *M. rosenbergii* adults, based on the hardness of the exoskeleton and internal setal development, has been established by Peebles (1977). The general physiological events of the crustacean moult cycle, according to Skinner (1985), are summarised below:

- Premoult (Stage D): Calcium and other materials are reabsorbed from the 'old' exoskeleton promoting its degradation, and a 'new' exoskeleton is formed beneath the old one. Separation of the epidermis from the old exoskeleton (apolysis) is evident. Enlargement of the epidermal cells also occurs.
- Moult (Stage E): The animal emerges from the old exoskeleton with a newly synthesised and pliable one. Moulting is accompanied by rapid uptake of water, resulting in an enhancement of animal size.
- Postmoult (Stage A and B): Deposition of calcium and other materials resulting in the hardness of the exoskeleton.
- Intermoult (Stage C): During the period between moults, the water absorbed during moulting is gradually replaced by tissue growth, and organic and mineral reserves are stored.

Changes in the biochemistry and physiology of various tissues occur during the crustacean moult cycle, and have been reviewed by Chang (1995). Some specific aspects for *M. rosenbergii* follow. In the premoult stage, ionic changes occur in different body compartments. Calcium, which is transferred from the old exoskeleton to the extracellular fluid, is excreted or carried to the hepatopancreas for storage. As a consequence, an increase in the concentration of calcium in the hepatopancreas and haemolymph is observed, rather than a decline in the ion concentration of the whole body (Fieber & Lutz 1982). In the early postmoult stage, exoskeleton calcium increases while calcium levels in the extracellular fluid and hepatopancreas are depleted. Such changes during the moult cycle reflect the importance of calcium in the exoskeleton (Fieber & Lutz 1984).

Changes in net water transport in *M. rosenbergii* perfused midgut during the moulting cycle were demonstrated by Mykles & Ahearn (1978). The water flux rates were elevated in animals approaching ecdysis and much reduced in the postmoult stage. According to these authors, the midgut may be the major site of water absorption at ecdysis.

Ecdysis and growth in crustaceans are affected by several extrinsic factors, such as temperature, photoperiod, water alkalinity, food availability and others (for a detailed review, see Chang 1995). Reproductive moulting in *M. rosenbergii* is enhanced in 12L:12D, 32°C conditions (Justo *et al.* 1991). Prawns held in high alkalinity water moult more frequently, but no enhancement of growth rate is observed (Latif 1992 *apud* Latif *et al.* 1994). Postlarvae and juveniles show optimum growth in the temperature range 29 to 31°C (Díaz-Herrera *et al.* 1993a) and growth rate is reduced with increasing salinity (from 0 to 20 p.p.t.) (Díaz-Herrera *et al.* 1993b).

The moulting cycle is under hormonal control (as reviewed by Skinner 1985; Fingerman 1987; Hopkins 1992; Lachaise *et al.* 1993; Chang 1995). In brief, a moult-inhibiting hormone (MIH) is secreted in the ganglionic X organ and transported to the sinus gland for storage and release. Moult-inhibiting hormone acts upon an epithelial endocrine gland localised in the maxillary segment which is called the Y organ; this secretes ecdysteroids synthesised from dietary cholesterol. Recent evidence supports the hypothesis that 20-hydroxyecdysone might be the moulting hormone. Wilder & Aida (1995) reported that an ecdysteroid 'surge' occurs in the late premoult stage; the predominant ecdysteroid was observed to be 20-hydroxyecdysone, followed by high polarity immunoreactive products (HPP). Spaziani *et al.* (1997) found that MIH released from the eyestalk occurs by means of an ecdysteroid feedback mechanism. The Y organ is negatively regulated, i.e. when the output of MIH by the XOSG complex is reduced, then the moulting hormone is secreted in greater abundance, and moulting events start.

In addition to the inhibitory regulation of the crustacean Y organ, there is evidence for the presence of a stimulatory factor. This factor, methyl farnesoate (MF), which is the precursor of the insect juvenile hormone, is synthesised and secreted in the mandibular organ and has already been identified in *M. rosenbergii* (Sagi *et al.* 1991). However, its involvement in the moulting of this species remains unclear (Wilder & Aida 1995; Wilder *et al.* 1995). There are difficulties in administering MF in experimental work, since it is hydrophobic. These have been overcome by Abdu *et al.* (1998b), who showed that this hormone could be introduced into *M. rosenbergii* larvae through a vector, *Artemia*, which had been cultured in a lipid medium enriched with MF. These authors found that the administration of MF retarded larval growth (carapace length) and the stage-specific morphological features between larval stages V and IX. Furthermore, Abdu *et al.* (1998a) found that MF significantly affected the patterns of metamorphosis and the appearance of intermediate individuals which exhibit both larval and post-larval morphology and behaviour. The relative abundance of these intermediate forms increased from 2% in the control to 32% when the MF concentration was high, suggesting that this hormone has a juvenoid effect.

3.5 Autotomy and regeneration

Autotomy refers to the process by which animals shed a part of their body, either as a result of damage or as a voluntary (spontaneous) act. It involves breaking part of the skeleton, whether internal or external, as described in detail by McVean (1982). In decapod crustacea there is a specific fracture plane for each appendage that can be autotomised. The process of autotomy occurs at the base of the ischial joint with the involvement of the levator muscles which, through their acute contraction, allows the preformed breakage plane to separate.

In *M. rosenbergii*, the most frequently autotomised appendages are the second pereiopods (chelipeds). As discussed earlier, the length of the male chelipeds is one of the characteristics of dominance within a population. When the male chelae reach a critical length in relation to the body length, the male voluntarily sheds both chelae at moult, and with the following moult a cycle of chelae regeneration starts. According to Schmalbach *et al.* (1984) the critical point above which autotomy can take place is a body length to chelae length ratio of 1:2.8. These authors suggested that this autotomic behaviour could be of great advantage as it leads to a succession of dominant males. This rotation would increase the genetic variability within a specific population.

Following autotomy, epidermal cells located on the periphery of the resulting stump enlarge and migrate. After several weeks, a papilla is formed as a result of a blastema erupting through the scab. The regenerated appendage is enclosed within a protective sheath which is released at ecdysis (Skinner 1985).

There is a close relationship between regeneration and moulting, so that regeneration only occurs during the proecdysial period. Thus an animal missing a single limb does not form the new one until it passes through the next moult cycle. However, the onset of preparations for moulting and intensive regeneration may occur much sooner in animals missing a large number of appendages (Skinner 1985).

The occurrence of antennule regeneration replacing the eyestalk (known as heteromorphosis) has been reported in cultured *M. rosenbergii* (Nevin & Malecha 1991). They may be functionally similar to normal antennules and may respond to mechanical and olfactory stimulation. This hypothesis is corroborated by Mellon *et al.* (1989) who demonstrated that the sensory axons of heteromorphic crayfish antennules are connected with the olfactory lobe of the brain.

3.6 Osmo-ionic regulation

Macrobrachium rosenbergii inhabits both freshwater and brackishwater environments during its life cycle. Therefore, each larval developmental stage, in addition to juveniles and adults, must be able to face the problems related to a hypo-osmotic medium, i.e. control of the volume of the haemolymph, prevention of ion loss and compensatory uptake of ions from the medium.

Although knowledge about larval osmoregulatory capability of this species is of great importance, there is a general lack of information on this topic. In a recent review, Charmantier (1998) summarised different types of the ontogeny of osmoregulation in crustaceans and noted that in decapod larvae, only a few species exhibited the same adult ability to osmoregulate, immediately after hatching. Like *M. rosenbergii*, *M. petersi* also migrates to estuaries to spawn and exhibits this pattern, since first-stage larvae are able to hyper-hypo-osmoregulate (Read 1984). According to this author, there is a relationship between the osmoregulatory capability of the developmental stages and their field distribution. The first zoeal stage of *M. petersi* is found both in freshwater and brackishwater, and has a strong ability to osmoregulate. From the second stage onwards, the larvae lose the ability to osmoregulate in freshwater and thus are confined to estuaries. The ability to osmoregulate is recovered when larvae reach metamorphosis.

The first zoeal stage of *M. rosenbergii* is able to survive for a few days in freshwater, suggesting that these larvae also display a strong ability to osmoregulate. Evidence for a progressive adaptation to freshwater during the ontogeny of *M. rosenbergii* is indicated by a decrease in the slope of the osmoregulation curves and a decrease in the isosmotic value (Harrison *et al.* 1981). Further evidence of such adaptation was demonstrated by Agard (1999), who found that the larvae of *M. rosenbergii* show a tendency to increase the rate of ammonia excretion as salinity decreases, under experimental conditions. Sandifer *et al.* (1975) showed that early PL are able to hypo/hyper-regulate the osmotic pressure of their haemolymph, in a wide range of salinity. However, the hyporegulatory ability is lost during the development to adulthood (Castille & Lawrence 1981; Stern *et al.* 1987; Funge-Smith *et al.* 1995). In fact, such loss can be an adaptive advantage, since the juveniles migrate to the adult habitat, i.e. to a freshwater environment. The difference in the patterns mentioned above suggests changes in the ontogeny of osmoregulatory capacity in *M. rosenbergii*, as reported by Read (1984) for *M. petersi*.

Macrobrachium rosenbergii is also an effective regulator of the major ions, when exposed to a wide salinity range (Stern *et al.* 1987; Funge-Smith *et al.* 1995; Wilder *et al.* 1998). Haemolymph sodium and chloride concentrations are hyper-regulated in salinities below the iso-ionic point (0–15 p.p.t.), and in salinities above the iso-ionic point the concentration of both ions follows that of the medium. Calcium and potassium ions are hyper-regulated at all salinities, whereas magnesium ions are always maintained at a lower concentration than that of the medium. This species can also regulate oligo-elements, such as bromide and strontium (Funge-Smith *et al.* 1995). The haemolymph bromide concentration was hyper-regulated from freshwater up to the iso-ionic point, whereas strontium was hyper-regulated until 18 p.p.t. In higher salinities, bromide levels followed those of the medium, whereas strontium was maintained hypo-ionic. These data suggest that both ions may have a physiological role in this species.

Examining the crystalline structure and ionic composition of the cuticle, Wilder *et al.* (1998) found that it was comprised principally of an α-chitin-like material, and calcite (calcium carbonate). Calcite accounted for 25% of total bulk weight in freshwater, while total sodium, potassium and magnesium compounds comprised less than 2.5% of this total. Although contents of these three ions increased nearly two-fold in response to changing salinity, calcium levels remained relatively constant. Wilder *et al.* (1998) considered that this may signify a possible role in preventing excessive titres from arising in the haemolymph under initial exposure to high salinity. However, these authors postulated that the cuticle might also serve as a reserve for maintaining calcium levels in the haemolymph.

The production of hypotonic urine, with respect to blood, is one of the important mechanisms which allows the achievement of high blood ion concentration in dilute media. According to Stern *et al.* (1987), *M. rosenbergii* may produce hypo-osmotic urine when exposed to freshwater, whereas in brackishwater they may produce iso-osmotic urine.

The isosmotic point of several *Macrobrachium* species is also directly related to species biotopes. Thus, species found in freshwater and brackishwater environments show higher values of their isosmotic points when compared to species found exclusively in freshwater (Moreira *et al.* 1983). The isosmotic point of *M. rosenbergii* adults is about 440 mOsm (Singh 1980); this low value, correlated with its pattern of osmoregulation, follows a trait shown by truly freshwater crustaceans (Mantel & Farmer 1983).

The osmotic and ionic concentration maintenance processes in freshwater crustacean haemolymph, through mechanisms of ion uptake and re-absorption, are regulated by neuroendocrine factors. In hyper-regulating crabs, a water-soluble factor found in the thoracic ganglion decreases water influx, while an acetone-soluble factor increases water influx. Dopamine, found in the pericardial organ, and cyclic AMP (adenosine 3′,5′-cyclic monophosphate) increase sodium uptake in the gills (Kamemoto 1991; Péqueux 1995). A series of studies carried out on the prawn *M. olfersii* corroborate the evidence for hormonal control of salt transfer and water permeability.

McNamara *et al.* (1990) demonstrated that eyestalk ablation affects haemolymph Na^+ concentrations during acute salinity exposure and suggested that the influx of sodium into the haemolymph, through the Na^+/K^+-ATPases located in the gill of *M. olfersii*, is at least partially modulated by a factor located in the eyestalks (or released from them). McNamara *et al.* (1991) suggested that neurofactors located within the thoracic ganglion may alter the apparent ionic permeabilities of this freshwater prawn.

Santos & McNamara (1996) proposed a model of osmoregulation for *M. olfersii* facing a freshwater environment. The animal hyper-regulates the osmolality and ionic concentrations of its haemolymph primarily through active salt uptake by means of Na^+/K^+-ATPases located in the gills and salt re-absorption from the urine by the antennal glands. Passive water entry is restricted by low osmotic permeability and water gained osmotically is excreted by the antennal glands by means of dilute urine.

3.7 Larval development

The eggs of *M. rosenbergii* are slightly elliptical, with a long axis of 0.6–0.7 mm, and are bright orange in colour until 2 or 3 days before hatching, when they become grey–black (Ling 1969). The larvae hatch as zoeae (Plate 1, facing p. 220), i.e. they typically utilise their thoracic appendages to swim, differing from penaeid shrimp which hatch as nauplii that are morphologically less developed and use their cephalic appendages to swim. First-stage zoeae are just under 2 mm long (from the tip of the rostrum to the tip of the telson). The zoeae are strictly planktonic, swimming upside-down within the water column and exhibiting positive phototaxy. Larvae, as well as adults, are omnivorous, mainly eating zooplankton but, in the absence of living food, they are able to feed on small particles of organic material (Ling 1969).

The larval development of *M. rosenbergii* is metamorphic and typically prolonged with several instars. Variability in the number of larval stages has been observed for several decapods, including some palaemonids (Knowlton 1974; Ngoc-Ho 1976; Gore 1985). This irregular development was divided into different categories by Gore (1985). *Macrobrachium rosenbergii* seems to exhibit 'delayed development', with 'mark-time moulting' and/or 'terminally additive staging'. In mark-time moulting the zoeal stage moults but only a small change in morphology occurs, with a slight increase in size. These zoeae, after a period of time, either die or enter a normal moulting mode and therefore complete the developmental process. Uno & Kwon (1969) reported that from zoea VI onwards a considerable variation in larval body length occurs even within the same instar, this phenomenon becoming more evident in the later stages. Other palaemonids (*Palaemonetes* spp. and *Macrobrachium* spp.) also exhibit this type of irregular moult (Ngoc-Ho 1976). Terminally additive staging is similar to mark-time moulting, however the supernumerary stages only occur at the end of a normal development sequence, resulting in similar individuals, differing mainly in size. According to Sandifer & Smith (1979), irregular development may confer advantages to species that live in changing environments, such as estuarine areas. This variation in the planktonic phase of *M. rosenbergii* may help to ensure larval dispersal, thus enhancing the chances of survival.

As a consequence of this variability, studies on *M. rosenbergii* larval development also exhibit different results. Ling (1969) observed 11 moults until the larvae attained metamorphosis, but only 8 of them displayed morphologically distinct stages, while Uno & Kwon (1969) reported 11 morphologically distinct zoeal stages. From hatching to the fifth zoeal stage, each moult produces a distinct larval stage, but from the sixth stage onwards the development becomes irregular. The same occurs with *M. equidens* and another *Macrobrachium* sp. (Ngoc-Ho 1976). Both descriptions reported for *M. rosenbergii* coincide for the first to fifth zoeal stages, but the sixth, seventh and eighth stages in the description of Ling (1969) resemble the sixth-seventh, eighth-ninth, and tenth-eleventh, respectively of Uno & Kwon (1969). Table 3.1 shows a simplified characterisation for each of the 11 zoeal stages of *M. rosenbergii* described by the latter authors. Newly metamorphosed PL are about 7 mm long and are generally translucent, with a light orange-pink head portion.

Anger (1998) has discussed the patterns of growth in decapod crustacean larvae. According to this author, the equation $L = a.S + b$, describes the increase of body size (L: length) as a linear function of the number of instars (S) for several larvae of caridean shrimp. However, after metamorphosis this growth pattern is not followed, since PL show smaller size increments at ecdysis. According to Uno & Kwon (1969) newly hatched zoea I of *M. rosenbergii* are 1.92 (±0.02) mm body length. At metamorphosis, the increment is negative: while zoea XI are 7.73 (±0.81) mm, PL are only 7.69 (±0.65) mm. Larval growth (in terms of DW biomass) is exponential, with a specific growth rate (i.e. increase in weight per unit of DW per unit time) of 0.084 (Stephenson & Knight 1979).

Recent studies (Webster & Dircksen 1991; Knowlton 1994) support the hypothesis that MIH is secreted by neural tissue in the larval eyestalk of decapods, as well as in adults. The larval moulting process also exhibits a cyclical Y organ activity and the production of ecdysteroids. β-ecdysone titres increase rapidly during early premoult, reaching a peak at late premoult, and then dropping prior to ecdysis (McConaugha 1980; McConaugha & Costlow 1981). Two concepts involved in the commencement of the larval moulting cycle were proposed by Anger & Dawirs (1981). The first is the 'reserve saturation point' (RSP), which is the minimum time in the larval moult cycle when sufficient nutritional reserves are built up to allow moulting to the next stage, regardless of the availability of further food supplies. The second concept, the 'point of no return' (PNR), is the moment that zoea must moult, or remain in the same stage and eventually die. According to these authors, water and minerals are assimilated, the endocuticle is secreted, and MIH is secreted into the haemolymph during the postmoult period. During the intermoult, food uptake is necessary to generate further development. As the necessary reserves are accumulated, the RSP is attained and β-ecdysone synthesis begins. At the end of the intermoult

Table 3.1 Selected characteristics of *Macrobrachium rosenbergii* larvae and postlarvae. (Source: modified after Uno & Kwon, 1969; see also Plate 1, facing p. 220.)

	Characteristics						
Stages	Eyes	Rostrum	Antennal flagellum	Uropod	Telson	Pleopods	Pereiopods
I	Sessile						
II	Stalked						
III		1 dorsal tooth		First appearance			
IV		2 dorsal teeth		Biramous with setae			
V			2 or 3 segments		More elongated and narrower		
VI			4 segments		More narrow	First appearance of buds	
VII			5 segments			Biramous and bare	
VIII			About 7 segments			Biramous with setae	
IX			About 9 segments			Endopods with appendices internae	
X		3 or 4 more dorsal teeth	About 12 segments				Fully chelated (1st and 2nd)
XI		Many dorsal teeth	About 15 segments				
Postlarva	Rostrum with dorsal and ventral teeth; behaviour predominantly benthonic, as in adults						

period the PNR is reached. If enough reserves have been accumulated, premoult then commences and ecdysis occurs.

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3.8 References

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4

Broodstock Management

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This chapter provides information on the source, selection, collection, handling and management of broodstock prawns (*Macrobrachium rosenbergii*). Future research avenues are also discussed, including the necessity to develop a nutritionally complete broodstock diet (see also Chapter 13). Systems for hatching freshwater prawn larvae and for their enumeration are described, while details of larval rearing technology are contained later in Chapters 5 and 6.

4.1 Collection of broodstock

4.1.1 Source

Female prawns carrying eggs attached to the abdomen are commonly termed berried or ovigerous females. In practice, the most common source of broodstock for commercial hatcheries is adult prawns obtained from grow-out ponds, although it is also prevalent for farmers to obtain a number of wild broodstock from rivers and ponds every season. Broodstock normally includes only berried females; however, under extended holding conditions, adult males may also be collected. Under tropical conditions, berried females are available year-round in farm ponds containing adult stock, and therefore no shortage should be expected. However, even in tropical areas the percentage of berried females may vary during an annual cycle. For example, Rao (1991) reported that in Lake Kolleru, southeastern India, berried females could be found year-round but peak activity occurred during the warmer months of August to October. New (1990) noted that peak mating activity in the wild occurs at the onset of the rainy season. Varghese *et al*. (1992) reported that natural spawning in the capture fisheries of Kerala, southwestern India, was associated with the onset of the rainy season. Interestingly, in Thailand, gravid females are most readily observed in estuarine waters (5–10 p.p.t.), from November to January (S. Suwannatous, pers. comm. to M. New 1998), which is the coolest time of the year and the dry season. When breeding activity varies seasonally, some difficulty in obtaining sufficient numbers of berried females may be experienced, especially in sub-tropical and temperate areas during wintertime. In temperate climates, broodstock are typically obtained during Autumn harvests and maintained indoors in special temperature-controlled environments during winter (‘overwintering’). One of the advantages of obtaining berried females from ponds, rather than open waters, is that they suffer less damage (including less loss of eggs) during harvesting and transport (S. Suwannatous, pers. comm. to M. New 1998).

If berried females are not readily available from ponds, successful breeding easily takes place under controlled conditions, but it is not common practice for hatcheries to maintain broodstock. Most often the maintenance of captive stocks is restricted to experimental purposes or to those hatcheries located in areas where *M. rosenbergii* has been recently introduced and berried females are not yet locally available from ponds.

In the Indo-West Pacific region, where *M. rosenbergii* is naturally distributed, some hatcheries prefer to use berried females from natural waters based on the belief that wild females produce better-quality larvae than pond-reared ones. A seasonal decrease in the availability of wild broodstock associated with the onset of the rainy season should be expected. Moreover, in recent years the natural catch has been reduced drastically as a result of overfishing and the deterioration of habitat and spawning grounds (Tonguthai 1992).

4.1.2 Selection

Selection of females is typically based upon ripeness of eggs and clutch size (i.e. number of eggs) without regard to body size. Ripeness is indicated by egg colour. As eggs undergo development, their colour changes from bright orange to brown and finally to greyish-brown a few days before hatching. Females with brown to grey eggs are usually selected to bring into the hatchery. The normal practice is to collect them during partial or total harvests, but cast netting may also be acceptable. Some studies have provided fecundity estimates based on morphological parameters (Malecha 1983; Ang & Law 1991). Fecundity increases with female size but the number of larvae produced by females of the same size is quite variable. However, experienced hatchery technicians estimate the number of broodstock needed for producing the required number of larvae, normally reckoning that 500–1000 larvae will be produced from each gram of female wet weight (New & Singholka 1985; Cavalcanti *et al*. 1986).

In ponds where prawns are continuously harvested year-round, the selection of females based solely on ripeness and availability does not take advantage of the biological fecundity of larger females (i.e. selection regardless of size of female) and provides no control over the breeding value (i.e. genetic worth) of the broodstock (Malecha 1983). This practice may select both genetically superior and inferior prawns. The alternative use of a separate brood pond or tank would allow for control of the age and size of females used for breeding.

Female size should be considered when selecting animals for reproductive purposes. In general, females become reproductively mature at a weight of between 15 and 20 g, but berried females as small as 6.5 and 8 g have been reported by Ang & Law (1991) and Ra'anan *et al*. (1990), respectively. Some hatchery operators would prefer to use large females since the number of eggs produced per spawn is proportional to female size. However, though many see this as an advantage, some potentially negative impacts are associated with this procedure. Selecting broodstock as early in the production cycle as possible has been suggested to enhance the growth rate of the future progeny (Doyle *et al*. 1983). Taking berried females 3 months after stocking exerts an indirect selection of 28% per cycle on the weight-at-harvest, whereas the use of 6-month-old females would result in a 15% negative selection. Therefore, the selection of fast-growing, younger berried females for hatchery use, rather than choosing any large female, has a positive effect on the growth potential of future broods.

The control of broodstock age is difficult where continuous stocking and harvesting of ponds is practised. New (1995) pointed out that farmers might resist such management modifications because the earliest (small) maturing females tend to produce fewer larvae and hence a greater number of berried females would be required. However, smaller females have been shown to outperform larger ones in terms of egg production over a set period of time (Cavalli *et al*. 1998). Due to their higher moulting frequency, smaller females breed more often and consequently spawn more eggs. The use of younger, smaller females would also reduce the costs and time involved in rearing broodstock in ponds. Although few farms have broodstock ponds, selecting early, faster-growing females and rearing them in separate ponds until they present a higher fecundity would be a simple improvement that could have a profound impact on performance. This would also allow a more efficient use of diets formulated specifically for maturing animals.

In temperate areas where broodstock are normally collected during Autumn harvest (100–130 days post-stocking with 0.1–0.5 g juveniles) for overwintering indoors, both the larger males and females are typically selected from healthy populations. Here the larger females are not necessarily the fastest growing females, but rather those that either have not yet spawned or recently spawned. In this case, larger females are used for overwintering because of the higher fecundity associated with size and the limited number of hatchery runs conducted. Selection of the larger females for long-term holding allows more larvae per female, especially considering the low percentage of females ready to spawn simultaneously. Selection of the larger females from a good growing pond population would provide more eggs per female and prevent selection of stunted females. The recommendations of Doyle *et al.* (1983) and Cavalli *et al.* (1998) should be considered if a hatchery will be producing numerous cycles over a spawning season. Concomitant with this selection is the selection of males of equal or larger size to ensure adequate insemination of females. While fertilisation of females by smaller blue claw (BC) males has been observed in captivity, the huge energetic effort and time required to manoeuvre the female into a reproductive position would suggest that a small-sized male would be competitively disadvantaged. On average, successful mating by males of equal or larger size takes between 1 and 4 min. Successful fertilisation by smaller BC males can take two to three times as long (Thomas 1998).

Blue claw males are collected since they are the mature, reproductively active males to which mature females are attracted following postmoult. The larger BC males are usually the newest recruits into the BC population following the 'leapfrog' theory proposed by Ra'anan & Cohen (1985), as detailed in Chapter 16. Daniels (1993) demonstrated a decrease in the testicular index as the BC male ages (i.e. time post-BC metamorphosis). Since the testes of BC males almost exclusively contain mature sperm (Sagi *et al.* 1988) and may not produce new sperm, older males might provide less viable sperm for mating. This would suggest that the reproductive capacity of the BC male decreases over time and, therefore, newer BC males would have a higher sexual capacity.

Daniels (1993) also showed that BC males normally have an intermoult cycle of 3 to 4 months. Upon moulting, they shed their claws and go through a rapid moulting and regeneration of their claws until, after three to five moults, they become BC males again. It is assumed that these males would be similar to orange claw (OC) males and exhibit high somatic and low reproductive growth capacities. Therefore, selection of new BC males would allow for 3 to 4 months of sexual activity. To ensure the continual presence of reproductively active BC males, OC males or strong OC males (i.e. those with relatively long, spiny claws referred to as 'pre-transforming strong OC males' by Sagi & Ra'anan (1988)) must also be stocked. In the 'leapfrog' theory, these OC males would become BC males as they surpass the size of the existing BC males or as the older BC males die or moult out of the BC phase.

Regardless of the source or size of broodstock, some criteria should be carefully observed when selecting prawns for hatchery use. Prawns should be active, well pigmented and have no lack of appendages or any sort of bodily injury or damage. Prawns covered with algae or showing signs of not having moulted recently may indicate that either culture conditions were poor or the animals are not healthy. Though no information associating broodstock as a vector of diseases to larvae is available (Brock 1993), prawns should be carefully examined with regard to apparent disease infections. Prawns should also be thoroughly checked for the presence of external parasites. Berried females might be a possible source for various epibionts that may affect larval performance. Protozoa such as *Zoothamnium*, *Vorticella* and *Epistylis*, which are routinely found on the carapace, gill lamellae and egg masses of *M. rosenbergii* (Brock 1993), may eventually lead to larval mortality through the impairment of swimming, feeding and moulting.

4.1.3 Handling and transportation

For short distances, buckets may be used for transporting broodstock, but double polyethylene bags placed within insulated containers are necessary for longer journeys. It is advisable to displace all the air from the polyethylene bags and replace it with oxygen in a similar manner to that used for the transportation of postlarvae (PL). Once inflated, the bag should be tightly twisted, doubled over and tied off to prevent loss of oxygen and water during transit. Ice is often used to maintain low temperatures since a reduction in temperature lowers metabolic rates, increases survival, and reduces activity, oxygen consumption and nitrogenous excretion (Chen & Kou 1996). The optimal temperature range for transport seems to be around 19 to 20°C. A stable water temperature during transport is also essential for success. Schmitt & Uglow (1996) reported that sudden changes in temperature increased nitrogen efflux rates of *M. rosenbergii*, clearly indicating a stressful condition. At 19 to 20°C, 12 to 15 g of prawns per litre of water can be shipped safely for 42 h (Smith & Wannamaker 1983). The use of brackishwater (up to 8 p.p.t.) instead of freshwater did not result in any significant improvement in survival. Dissolved oxygen concentrations appear to be more closely related to survival rates than any other water quality parameter.

Only prawns in the intermoult stage should be selected for shipment. They should also be fasted for at least 24 h prior to transportation. Prawns usually have their rostrum cut or a plastic tube inserted on the tip of the rostrum to prevent damage to the polyethylene bags. The chelae are also usually tied with rubber bands or covered with tubing. Alternatively, animals may also be wrapped in plastic or nylon screens and placed inside 50 mm diameter perforated PVC pipes, which are then placed into double polyethylene bags. However, Smith & Wannamaker (1983) found that prawns packed unrestricted suffered lower mortality than immobilised prawns. Similarly, the use of mesh material to increase surface area resulted in no benefit.

Daniels (unpublished) found that placement of adult prawns in hauling tanks (470 L per section of tank) at 30 to 60 g/L leads to crowding of prawns into tank corners, leaving much of the water column and tank bottom void of prawns. Although survival was good for 24 h, prawns were obviously stressed. Therefore, a system to spread the prawns out or layer them within the water column using trays or shelving would probably be beneficial to survival and good egg quality.

As a preventive measure, in countries where its use is approved, berried females should be disinfected upon arrival at the hatchery by placing them into freshwater containing 0.2 to 0.5 p.p.m. of copper or 15 to 20 p.p.m. of formalin for 30 min, as recommended by New & Singholka (1985). Aeration should be provided during these treatments. However, while copper at the above levels is used to disinfect berried females in Brazil (Cavalcanti *et al.* 1986), current practice in Thailand is said to involve the use of much higher levels of formalin (50–100 p.p.m.) for 1 h prior to entry into the hatchery (S. Suwannatous, pers. comm. to M. New 1998).

4.2 Broodstock management

Management of broodstock normally encompasses those practices associated with typical pond production in grow-out ponds. However, in temperate climates, broodstock must be either imported or maintained in an indoor broodstock holding facility. Because of the length of time these prawns must be overwintered, broodstock must be properly managed to ensure their health and survival. In future, as efforts are made to domesticate and genetically improve *M. rosenbergii*, holding broodstock will become more commonplace in tropical environments as well, thus making good management practices, such as broodstock manipulation, universally important. Santos (1998) observed that unilateral eyestalk ablation may be used to anticipate the first indoor spawn, increase the number of mature females and diminish the time between each spawn. Young females (4 months after PL stocking) spawn about 20 days after eyestalk ablation and spawn again after about 30 days.

4.2.1 Holding systems

Holding systems vary in size and configuration depending on how many broodstock need to be held, and the length of time required for holding. Unless prawns need to be maintained for extended periods of time, such as for overwintering in temperate climates, holding systems can be relatively small and stocked at high densities. For overwintering, holding systems must be able to maintain broodstock for up to 6 months. Water temperature must be maintained above 25°C to prevent loss of eggs and water quality parameters maintained to prevent stress and maximise broodstock health.

The size of the system depends on the total number of broodstock needed to produce a given quantity of larvae. Survival rates at broodstock facilities at Mississippi State University typically ranged from 50 to 60% for females and from 30 to 40% for males (originally stocked as a mix of BC and OC males) over a 5- to 6-month holding period when stocked at 1 g of broodstock per litre of culture water in 6.1 m diameter by 1.2 m deep tanks (W. Daniels, unpublished). Usually no more than 5 to 10% of the females are ready to spawn at any given time (i.e. all females spawning within a 3-day period). To produce batches of 500 000 larvae, approximately 11 egg-carrying female prawns averaging 45 g each would be needed (a smaller number of larger prawns would also be effective). Therefore, a conservative estimate would require at least 440 female prawns be stocked to provide 500 000 larvae in 5 to 6 months (50% survival, 5% of females spawning at any given time). At least 110 males (44 BC and 66 OC males) would also be required (see section 4.2.2) to service these females. Although the number of broodstock required may seem excessive and cost prohibitive, it should be remembered that this system would support a continual supply of larvae from different batches of females (e.g. 5% of females available every few days or at least once weekly). Therefore, the hatchery design (tank size and numbers) would support a system of multiple batches of larvae.

Holding systems may be static, flow-through, or recirculating depending on the water source and the amount of time that the animals are held. Systems may be tanks or ponds. Ponds can be enclosed for overwintering to maintain water temperature. To maximise usage, structures (e.g. netting or shelters) should be provided in the water column and on the bottom which allow the animals to spread out and occupy the water column as well as the benthic area. The added benefits are a reduction in cannibalism and an increase in fecundity (i.e. reduction in aggressive encounters). Hanging small-mesh nylon netting vertically or horizontally in the water column is one method of providing additional surface area. These structures may also be buoyed using PVC piping and floats. Smith & Sandifer (1979) described different types and arrangements of structures which were tested for juvenile *M. rosenbergii* production and found that a layered habitat design consisting of alternating open and strip layers was best. They utilised a modified version of this (previously described in Sandifer & Smith 1977) for maintaining broodstock at their facility (Sandifer & Smith 1978).

4.2.2 Stocking density and sex ratios

For short-term holding, BC males and females can be held either individually or more often in communal tanks at a ratio of one BC male to ten females. Males usually develop a harem and defend it and their territory from other males. Once mating has occurred, the females are moved to darkened conditions and fed a mixed diet (see section 4.2.4). It is imperative that minimal disturbance of females occurs. Once the eggs have become grey and are thus due to hatch within a few days, the females may be transferred to a hatchery system. Many types of spawning systems are employed and these are described in more detail in this chapter (see section 4.3.1).

For long-term holding, the density of brooders in the holding tanks appears to influence the egg-carrying capacity of females such that the total number of eggs which eventually hatch is reduced at higher densities. A stocking density of one individual per 20 to 60 L and a ratio of 1 or 2 BC males per 20 females are recommended. If broodstock are collected in early to late October (April in the southern hemisphere) and larval production is planned for December or January (June or July in the southern hemisphere), then OC males should be stocked at a ratio of 2 or 3 OC males per 20 females in addition to the BC males. The OC males should weigh >35 g when stocked. If newly hatched larvae are needed after March (September in the southern hemisphere), then OC males should be stocked at 3 to 4 per 20 females to offset increased mortality of males over a longer holding period (Daniels *et al.* 1992). Varghese *et al.* (1992) recommended a sex ratio of either 1 : 3.75, 1 : 4, or 1 : 4.75 (male : female) for maximum oviposition in *M. rosenbergii*, while Malecha (1983) suggested 1 : 4 or 1 : 5. Sureshkumar & Kurup (1998) suggested a ratio of 1 BC to 4 females was optimal for oviposition and hatching; however, ratios of 1 : 2 and 1 : 5 also produced good results.

Sandifer & Smith (1978) described a closed recirculating system in South Carolina for maintaining broodstock, hatching larvae and nursing juveniles. In the broodstock system, they stocked prawns ⩾30 g in 2000 to 5000 L tanks at densities of 30 to 90/m^2 of tank floor with a male to female ratio of 1 : 4. Within each tank they placed an artificial habitat. These workers achieved an overall average of 62% survival over 5 months. Approximately 25% of the females were found to be ovigerous every 2 weeks.

4.2.3 Environmental requirements

Environmental requirements have not been defined for prawn broodstock, but it can be assumed that temperature plays a major role in the timing and intensity of spawning while salinity is more important in natural environments for larval production. Adult prawns are tolerant of a wide temperature range (18 to 34°C), but temperatures ranging from 27 to 32°C are believed to be optimal. In wild populations of *M. rosenbergii* from Lake Kolleru (India), peak spawning occurred when the water temperatures were between 29.0 and 30.5°C (Rao 1991). Chavez Justo *et al.* (1991) found that the growth rates and frequency of reproductive moults were enhanced by the elevation of the water temperature to 32°C rather than 24 or 28°C, even though the highest condition factor was obtained for females maintained at 28°C. Typically, broodstock are held in fresh or brackish (<15 p.p.t.) water at 27 to 32°C. Hatchability is higher when berried females are kept in brackishwater (New 1990, 1995). According to New & Singholka (1995), some hatcheries allow eggs to hatch in freshwater for simplicity, while others place the females in brackishwater (5 p.p.t.). Yet others place the females directly into larval rearing tanks containing 12 p.p.t. brackishwater. Immediate transfer from zero salinity into 12 p.p.t. does not appear to cause osmotic shock in berried females. Currently, hatcheries in Thailand find that keeping berried females in 3 to 5 p.p.t. water stimulates improved egg development (S. Suwannatous, pers. comm. to M. New 1998). Colder temperatures reduce the number of eggs, increase the time for egg development, and appear to promote fungal growth on eggs (Daniels *et al.* 1992). Females may drop eggs if temperatures are too cold (<25°C). Chavez Justo *et al.* (1991) also suggested that a photoperiod of 12L:12D and a temperature of 32°C increased the frequency of reproductive moults, compared to a photoperiod of 15L:9D. This is surprising since photoperiod typically does not play a major role in reproduction in tropical aquatic species.

As with other aquatic species, excellent water quality should be maintained throughout the holding period. The tolerance of prawn broodstock to normally toxic compounds has not been defined, but based upon existing knowledge for other life stages, some general guidelines can be provided. It can be assumed that the levels of ammonia (especially unionised), nitrite and nitrate should be minimised, with unionised ammonia and nitrite kept at negligible levels. Information concerning the effects of heavy metals on reproduction, either lethal or sub-lethal, is also not available, but extrapolations from the available literature (see Chapter 14) suggest a need to be extremely cautious. For *M. rosenbergii* larvae, the levels of cadmium, copper and zinc should not exceed 0.033, 0.176 and 0.268 p.p.m., respectively (Liao & Hsieh 1990). The median lethal concentration for 96-hour exposure (96 h LC_{50}) to lead nitrate ($Pb(NO_3)_2$) was estimated at 1.0 p.p.m. (Piyatiratitivorakul *et al.* 1994). The amount of organic materials, especially suspended solids, should be minimised to prevent the proliferation of heterogeneous bacteria, reduce biological oxygen demand, and prevent stress to the broodstock and eggs. Tanks should be kept clean by siphoning excess food and waste as often as needed.

4.2.4 Feeding strategies

Females are typically not fed when being held simply for larval collection (New 1990). However, broodstock held indoors for extended periods of time will require a nutritionally complete diet and excellent water quality to promote superior egg production and quality. Very little work has been done on broodstock nutrition even though it could potentially impact egg and larval quality. Chapter 13 provides a commentary on the limited information that is available.

Sandifer & Smith (1978) and Daniels *et al.* (1992) both described feeding strategies for maintaining broodstock indoors for extended periods. Daniels *et al.* (1992) stated that when commercially available pelleted diets are not nutritionally sufficient, supplements such as pieces of beef liver or squid, cut to the appropriate size, should be fed at least twice per week. On the day of supplemental feeding, 50% of the amount of the pelleted diet should be substituted with a dry weight equivalent of beef liver or squid. As beef liver and squid have moisture contents of approximately 80%, 1 kg of either one would be only 200 g by dry weight. The amount of feed fed per day should be divided equally into two feedings (early morning and late afternoon). Broodstock should be fed at a daily rate of 1 to 3% of total biomass. The feeding rate should be adjusted to match consumption. Sandifer & Smith (1978) fed prawns Purina Marine Ration 25 (a commercial diet) once or twice daily at 1 to 2% of body weight and provided supplemental feeds (squid, ground fish, spinach, etc.) *ad libitum* several times weekly.

4.3 Larval hatching systems, collection and enumeration

Current larval rearing technology is described in Chapters 5 and 6. Special facilities for hatching are rare. In the following section the development of separate hatching systems and larval enumeration is covered.

4.3.1 Larval hatching systems

Larval hatching systems come in many shapes, sizes and configurations, which depend on the needs of the hatchery. Larvae may be allowed to hatch in the tank in which they will be cultured, or they may be hatched in the broodstock holding system and then transferred to the larval culture tank. When larvae are to be hatched within the culture tank, females with brown to grey eggs are collected and placed into enclosures (nets or cages) within the tank. Once hatching has occurred, the females and enclosures are removed. Problems associated with this technique are cannibalism of larvae by females and the obstruction of water circulation by the enclosure.

A more easily controlled system utilises a separate hatching tank. Females collected from either a pond or a holding system may be placed into a hatching system where eggs are allowed to hatch, and stage I larvae are collected with either a collecting device or simply netted from the system. Females are typically stocked at high densities (0.2–0.3 females/L) in an enclosure that prevents them access to larvae once the eggs hatch. Short pieces of piping or other structures may be added to provide shelter for females. Larvae can be attracted away from the females using light to take advantage of their phototactic nature, and drawn towards a water flow to move them into another collection tank. Collection normally occurs at night when most hatching occurs. The tank may also be covered to prevent extraneous light sources and provide for daytime collection. Each larval culture tank is then stocked with stage I larvae collected over a period of 1 to 3 days.

Daniels *et al.* (1992) described a typical hatching system (Fig. 4.1) consisting of a hatching tank (300 L rectangular tank), larval collector (120 L circular tank), and a mixing tank or biofilter (120 L circular tank). Forty to sixty females with brown to grey eggs are placed into the hatching tank supplied with adequate habitat structures (e.g. a piece of pipe for each individual). The interior of the hatching tank is black except around the area where the overflow pipe is located. This area is painted with a lighter colour. Black-painted grating (e.g. egg crating or louver material) divides the tank into two chambers with the chamber for holding the females occupying about 80% of the tank volume. Water overflows from the hatching tank into the collection tank, passes through a 180 μm mesh screen located around a centre standpipe, and then flows into the

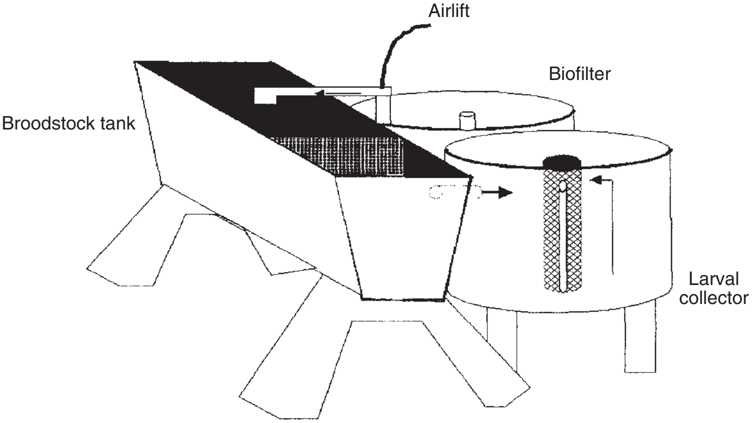

Fig. 4.1 A hatching system consisting of a 300 L broodstock tank and two 120 L circular tanks (larval collector and biofilter). (Source: Daniels *et al.*, 1992.)

mixing tank. Water is returned to the hatching tank from the mixing tank by airlifts.

Sandifer & Smith (1978) described a system for holding ovigerous females consisting of two 2000 L tanks (1.83 m diameter × 0.76 m deep) attached to a recirculating water system. Each tank contained artificial habitats and could accommodate up to 130 females/m^2 of tank floor and provide excellent survival ($\geqslant$90%) for 3-week hatching periods. The system was maintained at 28 to 30°C and 12 p.p.t. salinity using synthetic seawater. The two holding tanks were connected to a smaller larval collecting tank. The larvae were allowed to hatch in the tanks and were automatically harvested by the gentle siphoning action of water from the holding tank to the collection tank where larvae were retained. Although they expressed considerable variation in production, they averaged 46 600 larvae/day.

The Universiti Pertanian Malaysia developed a broodstock holding system (Fig. 4.2) that allows for maintenance of individual broodstock and natural water flow to remove larvae into a separate tank upon hatching (K. Ang, pers. comm. to R. Smullen 1995). It consists of a shallow raceway approximately 1 m × 0.5 m (H × W) and can either be constructed as a flow-through or recirculation system. Chambers are divided by screening with a mesh size large enough to allow the larvae to pass through, but small enough (10 mm) to prevent the female moving into an adjacent compartment. The water depth should be approximately 0.5 m to allow sufficient covering of the adult female and provide a low flow rate. Each compartment holds an individual female and the top of the raceway is open to allow easy access to the females for feeding, maintenance and replacement following spawning. When the female spawns, the larvae are carried with the water flow through the mesh and through each compartment into the larval rearing tank. Larvae can then flow into a number of different larval rearing tanks.

Although natural incubation is by far the most common practice, hatching may also be performed by artificial (*in vitro*) incubation (Balasundaram & Pandian 1981; Mathavan & Murugadass 1988; de Caluwé *et al.* 1995; Das *et al.* 1996). The use of *in vitro* incubation is thought to increase the number of larvae released from a single egg clutch because berried females usually lose eggs as incubation proceeds. Wickins & Beard (1974) hypothesised that losses could amount to 31% of the initial egg number. Malecha (1983) observed that females maintained in ponds had a lower fecundity than those kept in the laboratory probably because of the continual sloughing off of dying eggs due to epizootic infestation. Ang & Law (1991) reported a similar observation and attributed the decrease in fecundity to the continual consumption of eggs by females and the loose nature of grey eggs, which would make them more prone to physical losses. To offset losses, eggs should be manually collected from females a few days after spawning, preferably within 3 to 5 days.

In vitro incubation increases not only the number of larvae released, but also the breeding frequency of females relieved from the task of incubation (Damrongphol *et al.* 1991). Recently, a successful disinfecting protocol for *M. rosenbergii* eggs using formaldehyde, hydrogen peroxide and a commer-

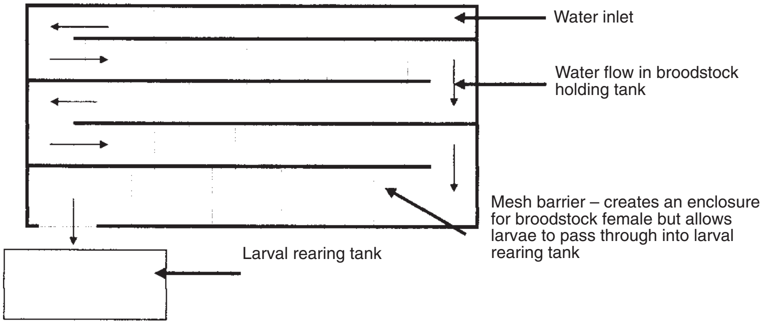
Water inlet
Water flow in broodstock holding tank
Mesh barrier – creates an enclosure for broodstock female but allows larvae to pass through into larval rearing tank
Larval rearing tank

Fig. 4.2 Broodstock spawning system developed by Universiti Pertanian Malaysia, which allows for maintenance of individual broodstock and natural water flow to remove larvae into larval tank

cial antibiotic and anti-fungal solution has been developed (Caceci *et al.* 1997).

Hatching occurs naturally under estuarine conditions and, as noted in section 4.2.3, egg hatchability is increased in brackishwater rather than in freshwater. de Caluwé *et al.* (1995) found that a combination of 6 p.p.t. salinity with temperatures of 26 to 28°C is optimal for the incubation of *M. rosenbergii* eggs. However, larvae obtained from eggs incubated at 25°C showed a higher resistance to temperature fluctuations than those from eggs incubated at 28°C (Gomez Diaz 1987). Temperatures above 30°C may prompt the development of protozoa and other undesirable micro-organisms (Brock 1993). The light regime does not seem to affect egg hatchability (de Caluwé *et al.* 1995) although direct sunlight should be avoided.

4.3.2 Enumeration of larvae

The number of larvae collected in either a collecting device or from a hatching system can be determined by enumerating the number of larvae in a known volume of water following a procedure similar to that described by Aquacop (1983). However, commercial hatcheries often omit the enumeration of larvae in every batch, believing that it is the number of PL produced that is important, not the number of larvae stocked (New & Singholka 1985; S. Suwannatous, pers. comm. to M. New 1998). It is important to remember that the numbers of larvae can only be accurately assessed when they are evenly distributed through the water column. That procedure consists of thoroughly mixing the water by hand and taking 8 to 16 samples of a known volume of water (e.g. a 30 ml beaker) and counting the number of larvae in each sample. Experience will dictate the number and methods used to get consistently accurate results. The average number of larvae/ml is then multiplied by the total volume of water in the collection tank to yield the total number of larvae. All larvae are then removed from the collection tank by siphoning or draining the tank, separated from any debris, and then placed into the larval culture system. This procedure is repeated for up to 3 days until the desired number of larvae are collected and stocked. If more than 1 day of collection is needed, a partial water exchange in the hatching system is advised for systems with no biofiltration and feeding of females should be reduced (Daniels *et al.* 1992).

4.4 Future research avenues

One of the major drawbacks of hatchery production in temperate climates is the asynchrony of egg development among females. Because only 5 to 10% of the females will typically hatch eggs within a 1- to 3-day window of time, large numbers of broodstock must be maintained over long periods of time (4–6 months) in temperate climates. This results in high costs and high mortality of broodstock. Methods to synchronise spawning would provide a larger number of females hatching eggs together, thereby reducing the number of broodstock required to produce the same number of larvae. Research to synchronise spawning through the endocrinological control of the timing of reproduction would provide major reductions in costs associated with holding facilities.

Broodstock must be held for extended periods of time indoors in temperate climates; this will also be necessary as prawns are domesticated and genetically improved. Under these circumstances, broodstock health and subsequent egg and larval quality are highly dependent upon good nutrition. Since these prawns are predominately held in tank systems, all of their nutrition must come from a well-balanced diet proffered by management. Unlike the diets typically developed for grow-out production (i.e. somatic growth), broodstock diets must provide the proper nutrition for optimal egg production (i.e. high-quality yolk deposition) and high-quality sperm production. Recent research results have demonstrated that the use of properly balanced diets may indeed affect reproductive performance. Das *et al.* (1996) found that a diet containing 40% crude protein with an energy level of 4000 kcal/kg increased egg production. Cavalli *et al.* (1999) demonstrated that high dietary levels of n-3 highly unsaturated fatty acids (HUFAs) and linoleic acid (18:2n-6) increased not only egg production, but also promoted the tolerance of 8-day-old larvae to ammonia stress. This clearly suggests the possibility of enhancing not only fecundity, but also larval quality, through improvements in maternal diets.

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5

Flow-through Hatchery Systems and Management

Eudes S. Correia, Somphong Suwannatous and Michael B. New

The original work of Takuji Fujimura and his team in Hawaii in the 1950s (Chapter 1) was based on the 'greenwater' principle, which involved the deliberate encouragement of phytoplankton (mainly *Chlorella* spp.) in the rearing water (New 1990), and was thought to improve water quality and increase survival to metamorphosis. However, high pH (9.5 and above) and algal blooms or crashes often caused larval mortality (Hudon *et al.* 1989). Nowadays, few prawn hatcheries, with some exceptions (e.g. Hsieh *et al*. 1989; Brown 1991; Thompson *et al*. 1992; see Chapter 17 – Mexico, Vietnam), use the 'greenwater' system, because commercial experience has shown that 'clearwater' systems are easier to manage and are thus more efficient. As they have evolved, flow-through hatcheries for freshwater prawns have been reviewed by New (1990, 1995) and described in detail in several manuals, including those by New & Singholka (1985), Valenti (1985), Cavalcanti *et al*. (1986), and Correia & Castro (1998). This chapter summarises and supplements the information presented in these manuals with the results of recently published research, and with the chapter authors' personal experience.

Flow-through hatchery systems are based on regular water exchange, in order to reduce toxic substances which accumulate in the rearing water. These originate from the metabolism of larvae and *Artemia* nauplii, and from bacterial decomposition of waste food, faeces, and dead organisms. Large amounts of brackishwater are therefore required for this type of hatchery. Following failures due to disease after two or three larval cycles, recirculation systems were abandoned in Thailand, where almost all hatcheries are now operated on a flow-through system. However, recirculation technology has been the subject of considerable research, which is now being applied in commercial hatcheries in Brazil and India (see Chapter 6).

Readers of the current chapter will quickly recognise that there are many different, sometimes conflicting, ways of managing flow-through prawn hatcheries. This chapter describes the art of flow-through hatchery management, based mainly on the personal experience of its three authors in Asia and Latin America; there is little science.

5.1 Site selection

For flow-through hatcheries, the choice of location depends partly on the ready availability of suitable water supplies. Sites should preferably be far from cities, harbours and industrial centres, or other activities which may pollute the water supply. The ideal site allows direct access to both freshwater and seawater. For this reason, coastal sites with sandy beaches and coral reefs are often preferred, but this is not a limiting factor. In Thailand, many hatcheries exist inland, far from the sea. Hatchery sites need to be located where there is a reliable power supply, because continuous operation of the aeration system is essential. A back-up generator is advisable. Another locational factor which needs to be considered is proximity to the major nursery or grow-out pond locations (the market for postlarvae). However, it is possible to transport postlarvae (PL) successfully for very long distances by road, rail or air, so this is not a limiting factor.

The brackishwater which is necessary for prawn hatchery operation is obtained by mixing seawater and freshwater, and needs to be of high quality. The freshwater used for this purpose should be as close as is feasible to potable quality and be carefully analysed during site selection concerning its physical, chemical, and biological characteristics. This is particularly important in regions where the use of pesticides, herbicides, and fertilisers is intensive. However, while potable freshwater is ideal, the cost of pre-treated water supplies would not normally be economically feasible. In practice, for example in Thailand, freshwater sources for prawn hatcheries include rivers, irrigation canals, and wells. The underground freshwater source used in the original Anuenue hatchery in Hawaii (Fujimura & Okamoto 1972), naturally filtered through coral, was an ideal which is difficult to match.

Some underground water sources are unsuitable because they have particularly high levels of iron and manganese, which are lethal to prawn larvae. Angell (1992) found that untreated deep wellwater in Bangladesh was toxic to prawn larvae. The cause was unknown but treatment with calcium hypochlorite eliminated the problem. This author also stated that adding 10 p.p.m. of the metal chelating agent EDTA to larval rearing water was beneficial. The acute toxicity of copper for prawn larvae was demonstrated by Ismail *et al*. (1990), who suggested that the copper level in rearing water should not exceed 0.05 mg/L and found that stage V larvae seemed particularly susceptible to copper toxicity. Chan *et al*. (1992) showed that the eggs of *Macrobrachium rosenbergii*, when incubated at 12 p.p.t. and 30°C, have a relatively high tolerance for heavy metals but recommended that the levels of cadmium, copper, and zinc in larval rearing water should not exceed 0.1, 0.057, and 2.97 mg/L, respectively. Copper was by far the most toxic of the three metals tested. Larvae affected by heavy metal toxicity were shorter and curved in appearance. Fitzgerald *et al.* (1991) recorded that in Guam, where a training centre's water supply was hard (calcium level not cited), larval survival appeared to be higher when bottled water rather than the supply from an adjacent well in a cave was used. Subsequently, the use of a recirculation system primed with rainwater was used (Landkamer 1994). The importance of calcium in all stages of the culture of freshwater prawns has been rather neglected but this topic is further discussed in Chapters 13 and 14.

Seawater supplies may originate either from the open sea, or sometimes from shallow beach wells where natural filtration helps to exclude harmful protozoa and bacteria. Usually locations are chosen where the salinity is 30 to 35 p.p.t. Although estuarine water can be utilised, when its salinity is above 16 p.p.t., this type of source is normally avoided because the level of micro-organisms predicates enhanced treatment before the water is used. Salt evaporation pans, particularly in Thailand, are a potential source of 80 to 100 p.p.t. water, which can be diluted for use in hatcheries; this reduces the cost of transporting seawater to inland hatcheries.

Both freshwater and seawater should be free from heavy metals (from industrial sources), marine pollution, and herbicide and insecticide residues (from agricultural sources), as well as biological contamination (indicated by the presence of faecal coliforms, which are common in residential and agricultural areas). For example, Law (1995) showed that the oil-spill dispersant Corexit 9527 found in Malaysian estuarine waters could inhibit the hatching of *M. rosenbergii* eggs. At 250 mg/L, 100% inhibition of hatching occurred. The recommended safety level was <40 mg/L. Tolerance levels for various substances are discussed in Chapter 14 but most of the research has been with juveniles rather than broodstock and larvae.

Table 5.1 shows the physico-chemical characteristics of water supplies that have been found suitable for freshwater prawn hatcheries; these are empirical data and should be viewed with some caution. Except where brine is used, seawater and freshwater are mixed to achieve the hatchery operating salinity of 12 to 16 p.p.t. This mixed water should also be within the range pH 7.0 to 8.5 and at least 5 p.p.m. dissolved oxygen (DO_2). Observations in Thailand indicate that brackishwater pH outside the locally favoured range of 6.5 to 8.5 causes decreased growth rate and, sometimes, causes mass mortalities.

5.2 Facilities

5.2.1 Physical plant

The size of the physical plant for each hatchery is site-specific, and depends on the desired production scale and the availability of resources. Facilities may be simple or highly complex. Most successful prawn

Table 5.1 Physico-chemical characteristics of water found suitable for use in freshwater prawn hatcheries. (Sources: Malecha, 1978; New & Singholka, 1985; E. Correia, pers. comm., 1999.)

Variables	Freshwater (p.p.m.)	Seawater (p.p.m.)	Brackishwater (p.p.m.)
Chloride (Cl)	40–223	19 000–19 657	6600–7900
Sodium (Na)	28–101	5 950–10 500	3500–4000
Potassium (K)	2–42	399–525	175–220
Calcium (Ca)	12–24	390–451	176–194
Magnesium (Mg)	10–27	1 250–1 343	458–542
Silicon (SiO_2)	41–53	3–14	6–29
Lead (Pb)	0.02	0.03	–
Copper (Cu)	0.02	0.03	<0.06
Zinc (Zn)	0.2–4.0	0.03–4.6	<3
Manganese (Mn)	<0.02	0.4	–
Iron (Fe)	0.02	0.05–0.15	0.3
Chromium (Cr)	0.01	0.005	–
Dissolved oxygen	>4	>5	>5
Total hardness (as $CaCO_3$)	120	–	2325–2713
Total dissolved solids	217	–	–
Ammonia (NH_3–N)	–	–	<0.5
Nitrite (NO_2–N)	–	–	<0.1
Nitrate (NO_3–N)	–	–	<20
Hydrogen sulphide (H_2S)	–	–	–
pH	6.5–8.5	7.0–8.5	7.0–8.5
Temperature (°C)	–	–	28–31

hatcheries in Asia are 'backyard hatcheries' where the facilities include water storage, mixing, and larval rearing tanks, as well as an aeration system, drainage facilities, and a water supply system. Often, hatcheries are enclosed, to maintain controlled environmental conditions and to reduce insects and dust. However, many simple hatcheries, especially where annual and diurnal temperature fluctuation is small, are open. Construction materials vary widely. Backyard hatcheries are often built of wood, and roofed with leaves (Correia *et al.* 1988). The influence of light is discussed in section 5.3.3.2 and Chapter 6. A typical hatchery diagram is shown in Fig. 5.1. Backyard hatcheries occupying 500 to 1500 m^2 of space close to Indian farmers' living quarters and capable of producing 500 000 PL/yr at a cost of US$ 7143 to 9524 in 1996 were described by Rao (1996).

5.2.2 Water storage and preparation tanks

The volume of freshwater and seawater holding tanks naturally depends on the anticipated demand for rearing purposes. Storage tanks may be square, rectangular or circular but this depends solely on the characteristics of the site and local material costs. Mixing tanks are also required for the preparation of brackishwater. For security reasons, it is necessary that two water preparation tanks, each with a volume equal to the total volume of all larval rearing tanks, are installed. Commonly, storage and mixing tanks are constructed in cement-covered brick and elevated to permit water to be supplied to the larval rearing tanks by gravity.

5.2.3 Larval rearing tanks

Larval rearing tanks may be round, rectangular, square or cylindrical-conical shape. Round tanks allow better larval distribution, but food distribution and tank cleaning operations become difficult, especially in the centre of the tank when tanks are too large. Such problems are not experienced in rectangular tanks; however, there is a tendency for larvae to concentrate in the corners and angles of these tanks, which should be rendered curved. Cylindrical-conical tanks present easy handling.

Larval rearing tanks may be constructed in fibreglass, polypropylene, cement-covered brick (Fig. 5.2) or asbestos (Fig. 5.3). It is essential that the

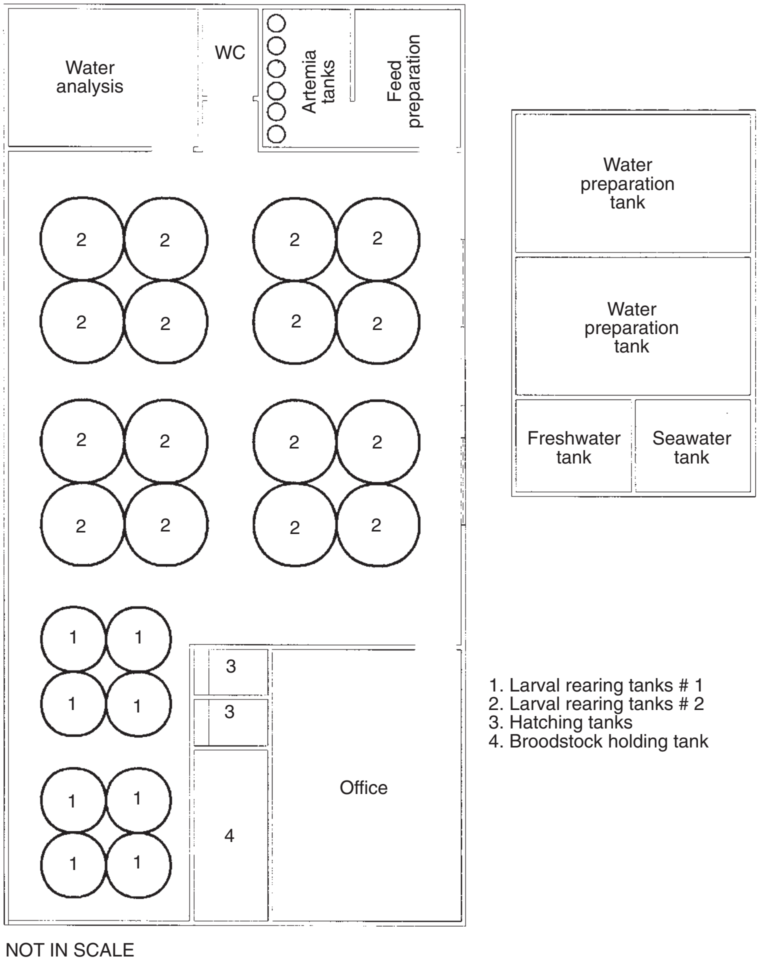

Fig. 5.1 Simplified layout of a flow-through hatchery system

materials used are inert. In particular, the interior of cement or cement-lined tanks must be painted with epoxyresin to avoid toxic chemicals leaching into the larval rearing water. Tank colour, like many other facets of prawn hatchery technology, remains controversial. Some operators observe that a dark (black, blue, green) interior gives the best results, because animals can detect their food more easily against a dark background and larval distribution throughout the tank is more uniform (thus ensuring proximity to food). However, other hatchery operators, claiming that larvae find their food mainly by tactile response, rather than sight, and that it is easier to observe the larvae and the cleanliness of the tank, prefer white tanks. Rodrigues *et al.* (1998) reported that they found no evidence that either sunlight or tank colour affected the capture or ingestion of food by freshwater prawn larvae. However, these authors found that greater numbers of PL were obtained with the use of black, as opposed to white tanks, irrespective of the incidence of sunlight. Furthermore, they reported that larger and heavier PL were produced when black tanks were used and sunlight was present. This matter is discussed further in section 5.3.3.2 and in Chapter 6.

Larval rearing tank capacity typically ranges from 1 to 10 m^3. Small hatcheries use 1 to 3 m^3 tanks to minimise water consumption and facilitate maintenance. However, 3 to 10 m^3 tanks are used in

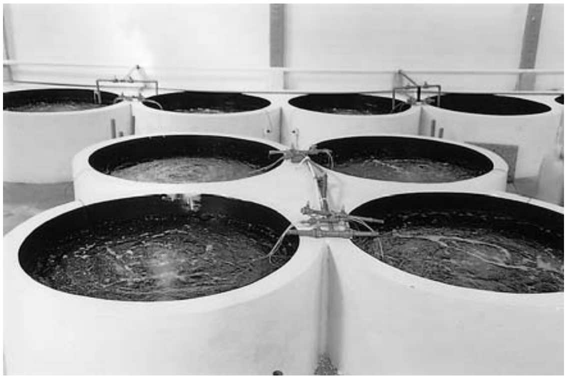

Fig. 5.2 Brick larval rearing tanks

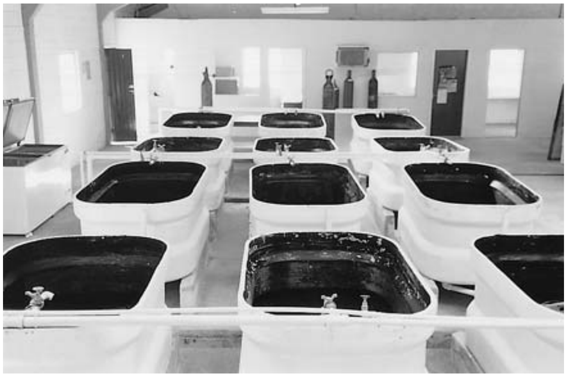

Fig. 5.3 Asbestos larval rearing tanks

medium- to large-scale hatcheries, in which maintenance needs special care. The depth should be approximately 1 m and the water column not more than 0.9 m. However, quite shallow water depth is reported to be used in China (Miao Weimin, pers. comm. 1999). The bottom of larval tanks is sloped slightly towards the drain. Drainage is provided by means of a turn-down PVC pipe having a diameter varying from 38 to 76 mm, which is protected by a 150 to 1000 µm nylon screen. The choice of screen mesh size depends on the larval development stage and needs to be just small enough to retain larvae during water exchange and siphoning processes. Larval tanks should be positioned so that they will drain by gravity when the turn-down drain is operated. Each tank requires an independent supply of brackishwater and air. A freshwater supply should be available close to the tanks, to reduce salinity when necessary for emergency use, and for tank cleaning operations between larval rearing cycles.

Some flow-through hatcheries (notably in Brazil) use two types of tanks sequentially to optimise the use of water and food, and to enhance management. In these cases, larvae are stocked and maintained at higher densities (300–500/L) until they reach the fifth larval development stage. After stage V the larvae are transferred to the larger tanks, decreasing their stocking density to 60 to 100/L. This system is not normally used in Thai prawn hatcheries which, though recognising that it is easier to manage small high-density tanks, consider that the damage and loss of larvae during transfer outweighs the apparent advantages.

5.2.4 Brine shrimp hatching tanks

These tanks are utilised to hatch *Artemia* cysts to produce nauplii as a food for prawn larvae (see Chapter 7). The most commonly used tanks are cylindrical-conical, made of transparent fibreglass or cement. Their dimensions vary, for example between 20 and 300 L in Brazil and between 500 and 1000 L in Thailand and Taiwan, according to the scale of the hatchery and the preference of the hatchery operator. In Brazil, operators calculate the total volume of the brine shrimp hatching capacity on the basis that 2 g of cysts require 1 L of water. In Thailand a lower cyst density is used (operators use 1 can of 400 g cysts per 500 L of water); thus a larger total *Artemia* tank capacity is required.

5.2.5 Water distribution and drainage system

In coastal freshwater prawn hatcheries topography and tidal movement need to be considered; direct seawater pumping being the simplest means of obtaining salt water. If the coastal characteristics indicate the existence of sufficient sub-surface water of suitable salinity, the use of wells should be considered. Another alternative is to draw water by means of perforated pipes protected by a 150 µm nylon screen buried approximately 1 m deep and connected to a suction system, or to use the simple shallow beach wells described by New & Singholka (1985). The sources of freshwater are discussed in section 5.1 above.

Pipework is required to distribute seawater and freshwater from storage tanks to mixing tanks, and from thence to supply brackishwater to each larval rearing and *Artemia* nauplii hatching tank. The optimum salinity for hatching *Artemia* can vary from 10 p.p.t. to full-strength seawater, depending on the source of cysts; thus a source of full-strength seawater may also be required in the hatchery. A supply of freshwater, as well as brackishwater, needs to be piped to each larval tank in order to allow for adjustments in salinity following siphoning, etc. All pipework systems need to be carefully designed to avoid 'dead' areas, where stale water can accumulate; 'ring-main' systems are one way of avoiding this.

Drainage of larval tanks is usually by gravity and the drainage canals should carry the drained water away without any contamination of the water sources. It is convenient to treat this water with sodium hypochlorite before discharge, in order to minimise environmental damage.

5.2.6 Aeration

A reliable 24-hour oil-free aeration system is essential for all hatcheries, in order to maintain dissolved oxygen levels in excess of 5 p.p.m. A standby blower should be available at all times, as well as an emergency generator where power supplies are unreliable (small portable and generally cheap systems are readily available). Radial 'Rootes-type' blowers are the most satisfactory and should have sufficient capacity to supply all operating tanks (water preparation, broodstock, larval rearing, and *Artemia* hatching) simultaneously, at a minimum level of 0.30 cubic feet per minute (0.50 m^3/h) of air for each cubic metre of water. The aeration system is a vitally important facet of the hatchery and every effort needs to be taken to protect it from accidental damage or disruption. Further suggestions for ensuring the reliability of aeration are contained in New & Singholka (1985).

Air distribution within hatchery tanks is normally through the use of porous stones (approximately 1/m^2 of tank bottom) or 20 mm PVC pipes, perforated with a $\frac{1}{32}$ inch drill, at intervals of 0.3 to 0.5 m. Good air distribution within each tank is essential to maintain even distribution of larval food and of the larvae themselves (which swim upside down through movements of their telsons). This keeps each larva in close and constant proximity to food particles, which most commercial hatchery operators view as essential.

5.2.7 Miscellaneous equipment

In addition to the major facilities described above, many other items are required for prawn hatcheries, including a means of measuring salinity (sometimes titration, often a densitometer, but preferably a refractometer; however, one of the authors (MBN) recalls that the pioneer Takuji Fujimura [see Chapter 1] became incredibly accurate in salinity determination by dipping his finger in the water and tasting it!), a microscope, a pH meter, a freezer, a refrigerator, some water heaters, various types of pipes, screens and buckets, a food blender, and siphoning apparatus for tank cleaning.

5.3 Hatchery operations

The total cycle of operations normally takes 30 to 40 days in an efficient hatchery. Careful attention to all details is essential to achieve success.

5.3.1 Water treatment

The volume of seawater required for daily use can be calculated by the following formula:

$$\mathrm{Vsw} = \frac{\mathrm{Vmt} \times \mathrm{Sbw}}{\mathrm{Ssw}}$$

where:

Vsw = salt water volume;
Vmt = mixing tank volume;
Sbw = the brackishwater salinity desired; and
Ssw = saltwater salinity.

As noted earlier, prawn larvae are normally reared at 12 to 16 p.p.t., the exact level depending on seawater availability and hatchery operator preference (based on local experience). Before use, brackishwater is allowed to stand, to allow any sediment to settle. It is then chlorinated for 1 day with 20 to 50 p.p.m. of sodium hypochlorite (10–12% of active chlorine). The final residual concentration, which should be 2 to 5 p.p.m. of active chlorine, depending on the original water quality, is then removed by aeration for at least 6h, or by adding sodium thiosulphate (5p.p.m.) directly in the mixing tanks; if sodium thiosulphate is used, the residual chlorine is removed within a few minutes. However, high concentrations of sodium thiosulphate can be toxic to prawn larvae (Chapter 6), so care in its use is essential. Further details of water treatment can be found in New & Singholka (1985). It is essential that the water has no residual chlorine before its use in larval rearing. Several problems caused by residual chlorine have been observed, and also with other treatments such as ozonization, and the use of ultraviolet (UV) sterilisation has been recommended. In Thailand, 40 to 50p.p.m. of formalin is sometimes used to eliminate protozoa and bacteria from the seawater used to prepare brackishwater. The choice between chlorine and formalin may depend on local cost-effectiveness. In some hatcheries the water is filtered using 5µm filters after chemical treatment and before distribution to the hatchery tanks. Many commercial prawn hatcheries omit this procedure. Upward-flow filtration is described by New & Singholka (1985).

5.3.2 Management of gravid females

Broodstock management is discussed in detail in Chapter 4.

5.3.3 Environmental requirements

5.3.3.1 Water quality

Water temperature is a critical parameter which governs the survival and growth rate of prawn larvae, and thus the duration of each larval stage. The optimum temperature range is 28 to 31°C (Rodrigues *et al*. 1991; Valenti 1996). Ideally it should be kept at 30°C. Gomez Diaz (1987) showed that larvae hatched from eggs incubated at 25°C exhibited a wider range of tolerance to salinity and temperature than those incubated at 28°C. Soundarapandian *et al*. (1995) found that while temperatures in the range 27 to 33°C had no significant effect on survival or the time of emergence of the first newly metamorphosed PL, there was a significant effect on the total rearing period of each batch. In their experiment, the average rearing period (the criteria used to 'terminate' and harvest the batch were not identified) varied from 42.1 days in November–December (when the average water temperature was 26.9°C) to 35.2 days in July–August (when the average water temperature was 33.3°C). Survival rates were generally rather poor in these observations, ranging from 26.0 to 35.8%. The best post-larval production rate achieved was 35/L, when water temperatures averaged 31.0°C.

Sudden changes in temperature, even by as little as 1°C, are more detrimental than gradual variation (New & Singholka 1985); adequate supplies of water at the same temperature should therefore be available for the replacement of siphoning losses or water exchange. Experience in Brazil shows that temperatures above 35°C can be lethal (in Thailand problems occur above 33°C) and, in both locations, larvae do not grow well below 25°C and the time to attain metamorphosis is much longer. In Thailand, water temperatures remain within the optimal range throughout the year, except for the months of November, December, and January, when night-time air temperatures may fall to 18°C and water temperatures below 25°C. During these months, thermostatically controlled water heaters are used to increase the water temperature above 27°C. This equipment requires careful use to avoid accidents.

Under natural conditions, *M. rosenbergii* needs brackishwater to complete its reproductive cycle; this characteristic needs to be simulated in the hatchery. Though estuarine conditions vary, in practice most hatchery operators maintain a steady salinity from hatching to metamorphosis; the salinity most frequently used is at least 12p.p.t., as recommended by New & Singholka (1985). However, the practice of some hatcheries is different. As noted in Chapter 4, many hatcheries place their berried females in slightly brackishwater, which improves hatching rate. Some hatcheries in Brazil hatch larvae at zero salinity while others use 5 to 6p.p.t.; the hatched larvae are then transferred to larval rearing tanks at 12p.p.t. within 3 to 4 days at the maximum. In Thailand there is a tendency for hatcheries not to use separate hatching tanks but to place berried females directly into the larval rearing tanks at 3 to 5p.p.t. In these cases the females are removed once the eggs have hatched and the salinity is increased to 12 to 15p.p.t. It is important that all the females in each batch hatch their eggs within 3 days to achieve a good larval survival rate (Miao Weimin, pers comm. 1999).

Continuous aeration is essential; interruptions in supply, which occur during the daily feeding and cleaning operations, should not be more than 30 min, to avoid larval stress. At least 5 p.p.m. of DO_2 should be maintained.

Water quality changes during the larval rearing process. Toxic chemicals increase, which are harmful to the larvae; they can be detected by increasing nitrite (NO_2-N) and ammonia concentrations (NH_3-N), whose limits should be <0.1 and <0.5 p.p.m., respectively. This topic is further discussed in Chapter 6. In order to maintain water quality, food needs to be rationed according to larval consumption; cleaning and water exchange should be regularly performed (see section 5.3.4); and adequate tank aeration should be maintained.

5.3.3.2 Light

The topic of light requirements remains controversial. The ‘greenwater’ larval rearing system, which has generally fallen out of favour in commercial hatcheries in the last decade of the twentieth century (New 1990, 1995), obviously requires light and the phytoplankton bloom provides shade for the larvae. However, in Thailand, where asbestos or plastic sheeting is used to cover open-air tanks, light seems to be of minimal importance. Indeed light is consciously kept to a minimum to prevent the growth of phytoplankton in ‘clearwater’ systems. Many backyard hatcheries completely cover their hatchery tanks with black tarpaulin to prevent potentially disease-carrying spray, caused by aeration, from being wind-transferred to other tanks (New 1995). On the other hand Raju & Nair (1992) described Indian hatcheries roofed with ‘Silkpaulin’, which allowed adequate penetration of natural light. In Taiwan, transparent roof tiles and special lamps for hatcheries were reported by Hsieh *et al*. (1989).

In many Brazilian hatcheries, a natural light intensity of 2000 to 2500 lux is supplied in indoor hatcheries through transparent roofs. Rodrigues *et al*. (1998) reported that when 2500 lux of artificial light was supplied, with and without sunlight incidence, the best larval survival was achieved when sunlight was present. However, good survival and productivity have been obtained at the UNESP Aquaculture Center (Centro de Aquicultura da Universidade Estadual Paulista) using a light intensity of only 250 to 800 lux (W. Valenti, pers. comm. 1999). Direct exposure to sunlight, however, has long been recognised to be detrimental (Fujimura & Okamoto 1972). In fully enclosed hatcheries in the UK in the late 1960s and early 1970s, where little or no natural light was available, circumstantial evidence concerning the spectral quality of light was obtained. The use of tungsten lamps or blue-black fluorescent tubes resulted in better larval survival to metamorphosis than the use of normal fluorescent tubes (which lack the near-blue UV wavelength found in sunlight). This observation remains to be confirmed. Further discussion of these matters is included in Chapter 6. The effect of altering photoperiod on larval performance is discussed in section 5.3.4.3.

5.3.4 Management of larval rearing tanks

The most frequent problems in hatcheries are usually caused by poor management. Errors during water exchange and waste siphoning, and during water quality control, are more often the cause of poor ‘survival’ than disease. Inadequate food is another major cause of failure. Good management entails constant monitoring of larval development and health.

5.3.4.1 Staging

The larvae of *M. rosenbergii* exhibit 11 developmental stages before metamorphosis into PL. Each stage corresponds to one or more moults (ecdysis), and displays particular identification features (Chapter 3). A rapid technique for moult staging has been described by Peebles (1977). Brazilian hatcheries observe the presence of PL from day 20 of rearing, but metamorphosis generally peaks between day 28 and day 32, depending on water temperature. Healthy larvae are active, display red-brown pigmentation, and in the absence of aeration they remain on the water surface. On the other hand, when in poor health, they do not feed well, practise cannibalism, display blue pigmentation, and swim irregularly. In the latter case, it is common to observe both dead larvae and waste food at the bottom of the tank. Larval survival depends on the culture methods and the standard of handling. In well-managed research hatcheries, survival rates up to 80% can be obtained. However, in commercial hatcheries, survival rates between 40 and 60% are more normal.

5.3.4.2 Stocking

Twenty years ago, Thai prawn hatcheries were using hatching tanks mounted above the larval tanks (New & Singholka 1985), similar to the original systems used in Hawaii. Nowadays, Thai commercial hatcheries do not normally use separate hatching tanks. Some 40 to 50 berried females with grey-black eggs are left in each 15 m^3 larval tank with 0.3 m of 3 to 5 p.p.t. water. Some 700 000 larvae hatch (but are not routinely counted) within the 2 days before the females are removed (see section 5.3.3.1). Following removal of the females, the water level is increased to 0.8 to 0.9 m and the salinity to 12 to 15 p.p.t.

Levels of sophistication in controlling the density of larvae vary considerably. Where separate hatching tanks are used the presence of larvae in the hatching tanks is verified by interrupting aeration and using a light source in one of the tank extremities to attract the larvae, since these animals have positive phototaxy. Once hatching has been confirmed, larvae are captured by siphoning into collecting buckets where they are counted and transferred to larval rearing tanks. Larvae may be counted in 250 ml samples, collected from the buckets and homogenised by aeration, which are then averaged. The average is multiplied by the bucket volume, thus providing a rough estimate of the total numbers present. The larvae are then stocked in the larval rearing tanks.

New (1990) reported that many early Hawaiian hatcheries stocked newly hatched larvae at 60/L (although some practised two-stage rearing with an initial stocking density of 160/L). Thai hatcheries used stocking rates of 30 to 50/L, although the quantity was determined rather by the number of berried females used than a conscious stocking of a defined number of larvae. Hsieh *et al*. (1989) reported that inland hatcheries in Taiwan at that time often used a multi-stage hatchery system with initial stocking rates of 300 to 1000/L in 500 L tanks, with transfers to larger tanks as the larvae grew.

Though not practised in Thailand, some Brazilian hatcheries currently use pre-stocking tanks (larval rearing tanks #1) until the fifth or sixth larval development stage (Correia *et al*. 1988; Valenti 1993, 1995). In these tanks 300 to 500 larvae/L are stocked, where they are maintained for approximately 10 days. After that, the density is reduced to 60 to 100 larvae/L by transferring to larval rearing tanks #2. Other Brazilian hatcheries, which do not use pre-stocking tanks, achieve a similar effect by stocking 100 larvae/L in the tanks, at first with a low water level. Later, the density is reduced by gradually increasing the water level. This increases feeding efficiency, as well as optimising the use of the stocking area, and eliminates the stress caused by transferring larvae mid-cycle.

Abreu *et al*. (1998) demonstrated enhanced survival rates when substrates (habitats) were placed in larval tanks, but this is not generally practised in commercial hatcheries.

5.3.4.3 Feeding

A critically important aspect of hatchery management is the larval feeding technique. Providing food of suitable nutritional quality, in a form and manner that keeps the food close to the larvae, at appropriate intervals, is essential. Larval nutrition and both live and inert feeds are discussed in Chapter 7, while feeding strategies for recirculation hatchery systems are covered in Chapter 6.

Barros & Valenti (1997) observed that stage I larvae of *M. rosenbergii* do not eat but feed well on *Artemia* nauplii from stage II. According to these authors the larvae become more omnivorous from stage VII onwards. However, as noted below, other hatchery operators present inert feeds (either moist or dry) to earlier larval stages and the merits of doing so remain a contentious issue.

In commercial Brazilian flow-through hatcheries, *Artemia* nauplii are fed to the larvae from the second larval stage onwards, on the assumption that stage I larvae use their own nutritional reserves and do not require an external food source. However, since some larvae progress to stage II within 24 h after hatching it is advisable to commence the feeding of *Artemia* from the first day. In those hatcheries in Brazil which use a two-stage rearing system, nauplii are provided to the #1 rearing tanks at 07:00, 11:00, and 16:00 h, and to the #2 tanks only at 16:00 h (after the last inert feeding). The quantities provided vary from 5 to 50 nauplii/larvae/day. Food consumption is observed during each feeding in order to adjust the amount for the next feeding time. It is important to maintain the density of nauplii above 1 individual/ml.

In Thai hatcheries, live food only is provided, several times per day, for the first 5 to 7 days of the larval cycle. From then onwards feeding of live food is carried out once per day in the evening and moist inert (egg-custard based) feeds are introduced three to four times per day. In Brazilian commercial hatcheries moist inert food or micro-encapsulated pellets are generally supplied from stage V onwards, at 07:00, 10:00 and 13:00 h. The amount of food depends on the larval development stage. Some Brazilian hatcheries present an inert feed before stage V. However, Barros (1996) showed that between stages II and VI, less than 50% of the larval population is able to capture the food; feeding this type of food too early may thus cause wastage and potential water quality problems. Currently (1999), some Brazilian hatchery operators provide one application of inert food per day to stage IV larvae, in order to wean the larvae on to the main type of food used in the #2 tanks. Soundarapandian *et al*. (1995) used *Artemia* nauplii at 5/ml of larval rearing water from stage I to VIII and at 10/ml from stage IX to PL in experiments in India. From stage III day onwards prepared feed (a mixture of chicken eggs, oyster meat, shrimp meal, water, beef meat, milk powder, vitamins, minerals and antibiotics (see section 5.3.4.5) was also given. Almost certainly the daily administration of prepared feed was not (or not fully) utilised until the larvae reached a later stage. In China, *Artemia* nauplii are fed from the third day after hatching onwards, while boiled fish flesh or egg is not fed until approximately day 10 (Miao Weimin, pers. comm. 1999).

Abstracts in English of larval rearing experiments in China are becoming available. Two are particularly relevant to this topic. Lin (1997) reported that, in a trial where prawn larvae were fed on *Artemia* nauplii from the first zoeal stage until metamorphosis, continuous light (L:D 24:0) appeared to increase food consumption and accelerate larval development. Under continuous light, ecdysis occurred at all times but was mostly between 12:00 and 18:00 h. In the other three groups (L:D 4:20; 8:16; 12:12) moulting occurred principally (93%) between 24:00 and 06:00 h. In a related paper, Lin *et al.* (1998) reported that the other environmental conditions were 15 p.p.t. salinity, 28°C, and a light intensity of 1500 lux throughout the experiment. Though there were no significant differences in the carbon and nitrogen contents of larvae reared under different photoperiods, results indicated that long periods of daylight, especially continuous light, may increase the growth rate, gross growth efficiency, and assimilation efficiency of prawn larvae, thus leading to enhanced production of PL.

In all hatcheries, careful observation, not only of the larval stage but also of feeding behaviour, determines the amount of feed presented on each occasion, whether it be live or inert. Sometimes larvae take the food and then discard it; this indicates a problem, such as poor water quality, diseased prawns, or unsuitable food particle size or composition. A typical feeding schedule used in Brazilian hatcheries is presented in Table 5.2. Overfeeding can cause water pollution, while underfeeding causes malnutrition, poor growth rates, cannibalism and poor survival.

Table 5.2 Live and inert feeding schedule during culture.

	Time (h)				
Larval development stage	07:00	10:00	11:00	13:00	16:00
I to IV	BS	–	BS	–	BS
V	BS	–	MEP/EC	–	BS
VI to PL	MEP/EC	MEP/EC	–	MEP/EC	BS

BS = brine shrimp nauplii; MEP = micro-encapsulated pellet; EC = egg custard.

5.3.4.4 Water exchange and tank cleaning

In all hatcheries there is some replacement of water every day, since the amount removed during the cleaning (siphoning) process needs to be replaced. Water exchange becomes (even) more important when inert feeding is commenced. In Thai hatcheries little or no water exchange occurs during the first 5 to 7 days, when only live food is provided. After that, the tank water is changed every day, or every second day, depending on water quality. When water exchange commences, the volume of water in the tank is reduced by an average of about 20 to 30% (much less than in Brazil, see below) and new brackishwater is added to return the water to the original level. When water exchange on one day is omitted (because water quality is deemed to be suitable) the level of exchange is increased to 40 to 60% on the following day. Some hatchery operators favour a greater water exchange every other day, since this stimulates moulting. Water exchange at an average of 20 to 30% per day continues until day 18 to 20. Then, when the first PL are observed, daily water exchange is increased to 50 to 60% per day. Again, water exchange is observed to stimulate moulting and, at this moment, metamorphosis to PL. Increasing the rate of water exchange thus shortens the period when metamorphosis of the batch occurs, thus facilitating hatchery management. In Thai commercial hatcheries, 60 to 70% of the larvae have normally metamorphosed by day 28. At this time the remaining unmetamorphosed larvae are transferred to another tank, rather than being discarded as was previously the practice (New & Singholka 1985). The salinity of the original tank is then reduced to 4 to 5 p.p.t. (rather than totally freshwater; this is simply to keep the *Artemia* alive, not because of any requirement of the PL) and artificial (dry) feed is introduced, in addition to *Artemia* and the egg-custard diet, thus acclimatising them to 'grow-out feed'.

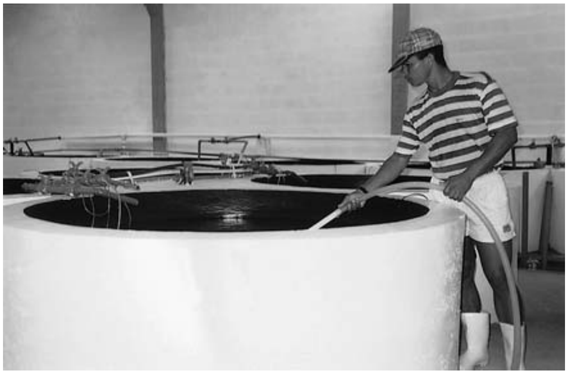

Fig. 5.4 Siphon cleaning system

Waste feed and faeces are removed by siphoning (Fig. 5.4). Before this process, aeration is interrupted to allow the particles to settle. The siphon consists of a 1 to 1.2 inch PVC pipe with one end flattened (like the old-fashioned type of domestic vacuum cleaner extensions) and the other connected to a flexible hose. The siphoning process not only removes metabolic wastes and excess feed but enables the operator to make daily observations of the larvae. At this time, the presence of dead larvae is the first sign of a problem, which might otherwise be missed. Later (from day 18 to 20 onwards) siphoning provides an opportunity to observe the presence of PL. Larvae or PL which are removed during the cleaning process are returned to the same tank. Once siphoning is over, aeration is restarted and, if water exchange is to be done that day, it normally occurs at this moment. In Brazilian flow-through hatcheries, 50 to 70% of the water in each tank is drained out daily, following which the original water volume is restored. It is important that the temperature of the replacement water is the same as the discharged water to avoid thermal shock. As in Thailand, Brazilian hatchery operators observe that water exchange is not necessary in the first few days of each larval cycle. However, in certain cases where water quality is observed to be very poor (perhaps due to an error in feeding, for example) total water replacement is necessary.

5.3.4.5 Hygiene

Good hatchery hygiene is important to control the incidence of disease. Massive blooms of *Zoothamnium*, *Epistylis* and hydroids, which are harmful to larvae, occur if hatchery hygiene is inadequate or if the incoming water is poorly treated. Regular disinfection of all equipment with a 100 p.p.m. sodium hypochlorite solution, followed by sun-drying, is recommended. The transfer of water and equipment from one larval tank to another without disinfection must be avoided. Good personal hygiene is also advisable. Further discussion of these topics is provided in Chapter 15. New (1990) noted that the use of antibiotics, and sometimes sulpha drugs, in larval rearing was commonplace. This practice is not normally publicised, and cannot be recommended. Hsieh *et al.* (1989) described the use of the antibiotics chloramphenicol and tetracycline, as well as furazolidone, formalin and iodine, in larval rearing; their indiscriminate use was reported to be a problem in Taiwanese hatcheries at that time.

5.3.4.6 Quality of postlarvae

Quality control is very important in all hatcheries. In research, efforts have been made to find ways of separating weak from healthy larvae, employing their negatively rheotactic and photopositive characteristics (Singh & Philip 1995). Such methods are potentially useful in disease and toxicological studies but, where larvae are observed to be weak in a commercial situation, it is more likely that the whole batch will be discarded than the strong separated from the weak. Some crustacean hatcheries use a stress-evaluation test as a method of quality control and a promotional tool when marketing their PL. Such methods can also be used in research, for example in nutritional and microbiological studies, but there is a need for the procedure to be standardised (Dhert *et al.* 1992). Recently, Cavalli *et al.* (2000) have described an experiment where the larvae of *M. rosenbergii*, either given a nutrient-rich diet (*Artemia* nauplii enriched for 24h with n-3 highly unsaturated fatty acids [HUFA]) and ascorbic acid (AA) or a nutrient-poor diet (*Artemia* nauplii starved for 24h) were exposed to ammonia. As expected, feeding the nutrient-rich diet resulted in higher n-3 HUFA and AA in the prawn larvae, as well as improving growth and metamorphosis rates. Exposing these two same-spawn groups of prawn larvae to six different levels of ammonia, compared to a control (no ammonia), demonstrated that from the moment that the effect of diet quality was analytically detectable in larval tissues, the ammonia test was able to distinguish between them. Differences in ammonia tolerance were observed as early as larval stage IV. This short-term ammonia toxicity test was shown to be a sensitive and reproducible criterion for larval quality and is therefore a potentially useful tool for hatchery operators.

5.3.5 Handling, harvesting and packing postlarvae

Newly metamorphosed prawn PL are about 7mm long and begin to swim and crawl like adult animals. In Brazilian flow-through prawn hatcheries, habitat substrates (e.g. pieces of screening material) are put into the larval tanks when PL are observed, to provide increased surface area and reduce cannibalism. Newly metamorphosed PL are quite salinity-tolerant. After approximately 90% of the larvae have metamorphosed, the Brazilian practice is to gradually add freshwater to the tank over a period of 2 days until the salinity reaches zero. However, New (1990) reported that this process can be achieved within 2 to 3h without stressing the PL with; current practice in Thai hatcheries is often to complete this within 3 to 4h. Post-larvae are typically acclimatised to freshwater (below 0.5p.p.t.) in Chinese freshwater prawn hatcheries within 6 to 8h (Miao Weimin, pers. comm. 1999). In Brazil, PL may remain in this environment at the final metamorphosing density for a maximum of 5 days, or are transferred to nursery tanks. During this holding stage, some hatchery operators feed their PL five or more times a day with an inert food (such as egg custard, spleen, cow liver, or a formulated aquafeed). Feeding is adjusted to ensure sufficient food to reduce cannibalism. Tanks are cleaned by daily siphoning and approximately 30 to 50% of the water is replaced.

In Thailand, after late metamorphosing larvae have been removed to another tank, the salinity for the PL is at first reduced to 4 to 5p.p.t. (see section 5.3.4.4). If PL have to be kept more than 5 to 7 days before transfer to grow-out ponds, they are transferred to a 10 to 20t holding tank into which nets or branches are introduced as habitats where moulting PL can shelter. Formulated aquafeeds, sometimes floating fish feeds (New 1990), and egg custard (but no spleen or liver) are fed. The density in these holding tanks, for periods of up to 1 month, is 1500 to 2000/m^2. Tank cleaning (siphoning) and a 40 to 50% exchange of water is carried out every 2 or 3 days.

Careful harvesting and counting of PL, for packing and shipping, is an important facet of successful hatchery operation. A method to separate post-larval prawns was devised by Martinez-Palacios *et al.* (1985), based on the rheotactic activity exhibited by post-larval prawns; this avoids the stress claimed to be caused by the dip-net harvesting technique described by New & Singholka (1985). However, Daniels *et al*. (1992) found dip-netting to be simple and effective and it remains common practice. For example, in Thailand, a large net (0.7 × 0.4 m) is used to harvest the PL from the holding tanks. Two thousand PL are allocated to each plastic packing bag (0.3 × 0.4 m) in 3 L of water. The bags are oxygenated for 3 to 5 minutes, after which the bags are closed with rubber bands. Postlarvae can remain in these bags for 24 to 36 h during transfer to farmers' grow-out ponds, which are sometimes many hundreds of kilometres from the hatchery.

In large Brazilian hatcheries, harvesting occurs daily before packaging. The water level and aeration in the larval tanks is reduced. Postlarvae move around the sides of the tank and are captured using dip-nets. After the number of PL is reduced, the rest are harvested externally during final drainage of the tank. Postlarvae are then concentrated in a smaller tank with continuous aeration to facilitate counting. They are then packaged or counted directly into holding tanks. Before packaging, PL are counted using a volumetric or a visual standard. In the first method, the PL contained in a certain volume or weight are counted, and this number is used as a standard. The second method consists of counting approximately 2000 to 3000 PL, after which they are transferred to a light-coloured bucket filled with 5 to 6 L of water. Next, other buckets are filled with the same water volume and PL are placed in them, thus visually matching the number of PL in the counted container. Sixty-litre plastic bags are used for packaging prawn PL at a density of 3000 to 5000 PL (10 mm size) in 12 L of water. The water is saturated with oxygen and a ratio of one-third water to two-thirds oxygen is maintained in each bag (Fig. 5.5) which, as in Thailand, is tightly fastened with elastic bands.

Vadhyar *et al*. (1992) found that introducing 10 to 15 mm pieces of floating translucent plastic straw as a habitat material in model transport containers for PL 10–15 *M. rosenbergii* improved survival time, compared to either no habitat, sinking black plastic ribbon, or sinking white folded netting. With plastic straw 100% survival was obtained after 72 h at 100/L and 24 h at 200/L packing densities.

In Thailand, PL are also transported in open plastic tanks (500–1000 L) containing 70 to 80% water if the transport time is short (1–2 h), thus significantly saving materials and labour. With aeration, each tank can accommodate 300 000 to 500 000 PL. Usually, 1 to 10 t trucks are used for transporting PL. A 1 t truck can accommodate about 500 000 PL in plastic bags. Generally the prawns are transferred by night. However, if the transport occurs during the daytime, additional precautions are necessary. The floor of the truck is lined with gunny-sacks, which helps to prevent heat transfer from the road and from the truck exhaust system. A temperature of 20 to 27°C is maintained by placing new supplies of crushed ice on top of these sacks every 2 to 3 h; this ensures a high survival rate during transport. Sometimes trucks with built-in cold storage are used to transport 1 to 2 million PL at a controlled temperature of 20 to 25°C. A stable water temperature during transport is essential for success. Schmitt & Uglow (1993) showed that sudden changes in temperature appear to cause stress, as exhibited by increased nitrogen efflux rates. Similar stress is caused by handling. In Brazil, either surface or air transportation is used to distribute PL. For transportation periods of more 6 h the temperature is kept between 20 and 22°C, in order to reduce metabolism and consequently cannibalism.

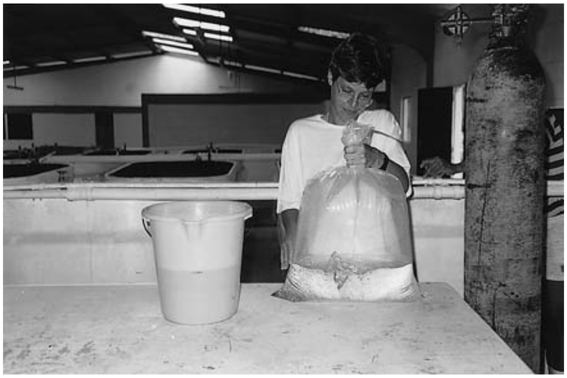

Fig. 5.5 Packaging postlarvae (PL) for transport

5.3.6 Production efficiency

Formerly, freshwater prawn hatcheries typically obtained 10 to 20 PL from each litre of larval tank capacity (New 1995). However, it is now common

Table 5.3 Characteristics of a typical 10 million/yr hatchery.

Larval rearing tank type	#1	#2
Number of larval rearing tanks	8	16
Effective volume of each tank (L)	900	1800
Stocking density (larvae/L)	400	75
Total larvae stocked per tank	360000	135000
Approximate period of culture (days)	12	25
Estimated survival rate (%)	75 (range 70–80)	50 (range 40–60)
Number of larvae to be transferred from #1 to #2 tanks	270000	–
Yield of postlarvae (PL/tank)	–	67500
Total yield of postlarvae/cycle	–	1080000
Annual production capacity (10 months operation)		10.8 million

for Thai backyard hatcheries to achieve, on a routine basis, 60 to 80% survival and thus a production rate of 40 to 50 PL/L. Fifty postlarvae per litre are also achieved in Brazilian flow-through systems (Parseval *et al.* 1989). A hatchery with eight #1 larval rearing tanks and sixteen #2 larval rearing tanks allows a production of 10 million PL/yr (Table 5.3). Production rates in recirculation systems are given in Chapter 6.

In 1995, 600 to 800 million freshwater prawn larvae were being produced annually from 50 backyard hatcheries in Thailand, sufficient to supply 6400 ha of grow-out ponds (Suwannatous 1996). Government hatcheries in Thailand, which stimulated the development of commercial hatcheries through a joint FAO–Royal Thai Government project 20 years ago (New *et al.* 1982), continue to produce PL for stocking in open waters (Chapter 22). At the end of the millennium, some over-supply of freshwater prawn PL existed; 1999 prices for 20- to 30-day-old PL (PL 20–30) were US$ 1.25/1000, the same as in 1993 (New 1995). However, further expansion of the sector in Thailand is predicted (S. Singholka, pers. comm. 1999), which may take up this slack.

5.4 Further developments

Refinements in practical techniques have occurred and differences in detail between various flow-through hatcheries exist, as demonstrated in the examples given in this chapter. In addition, research on recirculation systems has progressed and is being translated into commercial use (Chapter 6). Nevertheless, New (1995) noted that no fundamental change in non-recirculation hatchery technology (except for a general shift away from the use of 'greenwater') had been reported in the literature between 1990 and 1995. However, in 1996, the rearing of *M. rosenbergii* larvae in open earthen ponds was reported in Thailand (Tunsutapanich *et al.* 1996). This novel process was described in detail by Tunsutapanich *et al.* (1997). In this study, four 1600 m^2 ponds were filled with water of 10 p.p.t. salinity. Biological, chemical and physical treatments were applied to the ponds and continuous aeration was provided through tubing. No water exchange appears to have occurred during the cycle. Berried females (approximately 25 pieces/kg) were introduced into cages placed in each pond in sufficient numbers to produce two initial larval stocking densities – 4 and 6 million larvae per pond (2.5–3.75 PL/L). Naturally occurring plankton comprised the sole food available for the first week of the cycle (days 1 to 7). As the supply of natural food decreased, it was supplemented with *Artemia* nauplii (days 6 to 15), keeping the *Artemia* density above 10/L. These nauplii were partially (from day 12 to day 15) and then totally (after day 15) replaced with (adult) *Artemia* biomass, which was fed until day 21. From this stage onwards, farm-made egg-custard diets (containing chicken egg, mussel flesh, squid, etc.) and 0.5 to 1.0 mm particulate diets were fed until the PL were harvested. A natural growth of sea grass (*Ruppia maritima*) was observed after the first week and was thought to help to maintain good water quality conditions. A modified 60 m seine net was used for harvesting with the catching area having 18 to 20 meshes per inch. The first metamorphosing animals were observed after 13 days at the lower density and 14 days at the higher. Survival rates were estimated to be around 68% at both stocking densities. Since there was no significant difference in survival at the two densities used, the authors suggested that even higher stocking densities might be used profitably in future. Final harvests, achieved within 29 to 35 days, were 2.75 million PL at the lower stocking density and 4.05 million PL at the higher density. This novel technology offers significant opportunities for increasing the supplies of PL, decreasing the volume of *Artemia* cysts required, decreasing the consumption of water, shortening the larval cycle time (compared to concrete tanks), and utilising less labour. In addition, this technique offers the possibility that even the relatively unsophisticated backyard hatcheries may be less necessary in future. Research into improvements in this technique is on-going (S. Thongrod, pers. comm. 1999). One improvement being tested is the use of oxygen instead of air for aeration. Recently, the use of earthen ponds for rearing the larvae of another commercially important freshwater prawn, *M. nipponense*, has been reported (Wang & Qianhong 1999).

As mentioned in section 5.3.4.3, English abstracts of Chinese papers on *M. rosenbergii* research are becoming available, often in agricultural journals and fisheries magazines. Not only do these concern the topics discussed in that section, namely photoperiodicity (Lin 1997; Lin *et al*. 1998) but also a number of other subjects including larval rearing (Cui *et al*. 1995; Liu *et al*. 1995), hatchery and grow-out technology (Tang *et al*. 1996), and descriptions of experiences in a commercial hatchery (Chen *et al*. 1996). Unfortunately, only the title or an extremely brief abstract are provided for these papers in the AGRIS (International Information System for the Agricultural Sciences and Technology) abstracts, so it is impossible to include information from them in this or other chapters of our book. It is to be hoped that such research results will soon become available to a wider audience through publication, in English, in international aquaculture journals. Since China is now the major producer of farmed freshwater prawns (Chapters 1 and 17) it is certain that it has much to contribute to our scientific understanding of this topic.

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6
Recirculation Hatchery Systems and Management

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Conventional hatchery systems have been described in Chapter 5. This chapter deals with recirculation hatchery systems, which have been developed to minimise water losses and maximise water quality for raising larvae. Minimal water usage is very important for inland hatcheries, where water must be transported long distances or artificial seawater is used. Recirculation allows continuous or semi-continuous processing of water to remove nitrogen and solid wastes and disinfection for disease management. The use of recirculation systems in *Macrobrachium rosenbergii* hatcheries has several advantages over open systems. These include more stable water quality; lower water consumption; heat conservation; lower labour requirements; control or prevention of pollutants, parasites, predators and competitors; and enhanced feasibility of establishing inland hatcheries (Smith *et al*. 1976; Cohen & Ra'anan 1989; Griessinger *et al*. 1989).

6.1 Hatchery design

Hatcheries are designed to match the desired rate and timing of the production of postlarvae (PL). Past experience and literature reviews suggest that stocking rates of 40 to 100 stage I larvae/L and survival rates ranging from 40 to 80% are typical. Success is principally dependent upon hatchery design and management. Design criteria include lighting, systems for hatching and enriching *Artemia* (the principal food for prawn larvae), holding tanks for mixing and storing seawater, ease in disinfecting tanks and surrounding areas, and temperature control. Alarm and emergency back-up systems for all hatcheries are desirable to prevent catastrophic losses. Information on separate systems for hatching larvae and for the enumeration of larvae is provided in Chapter 4.

6.1.1 Static closed system

This system was developed in Brazil in 1984 and has been used by inland hatcheries (Valenti 1992; 1993a; 1996). Tanks and general management protocols are similar to those employed in open systems (Chapter 5). However, daily make-up water from larval rearing tanks is transferred to other tanks for processing and then to a biological filter instead of being discarded. After the nitrification process is completed, the water is returned to the rearing tanks.

Carvalho & Mathias (1998) described the static closed system in detail. Half of the rearing tank water is exchanged daily. Water removed from the larval tank is clarified by filtering it through a mesh screen (5 μm). It is then chlorinated (2.5 mg/L active chlorine) for 40 min in the treatment tank. The residual chlorine is removed with sodium thiosulphate ($Na_2S_2O_3$). After filtering the water again through a mesh screen (1 μm), the water is transferred to a large biological filter where it is circulated through the substrate for 2 to 3 days to complete the nitrifying process. The water is then returned to the larval rearing tanks. The system is composed of three biological filters, which are used on consecutive days and always in the same order. Each filter has a volume capacity equivalent to the total volume of the larval rearing tanks of the hatchery. The water flow in the system is shown in Fig. 6.1.

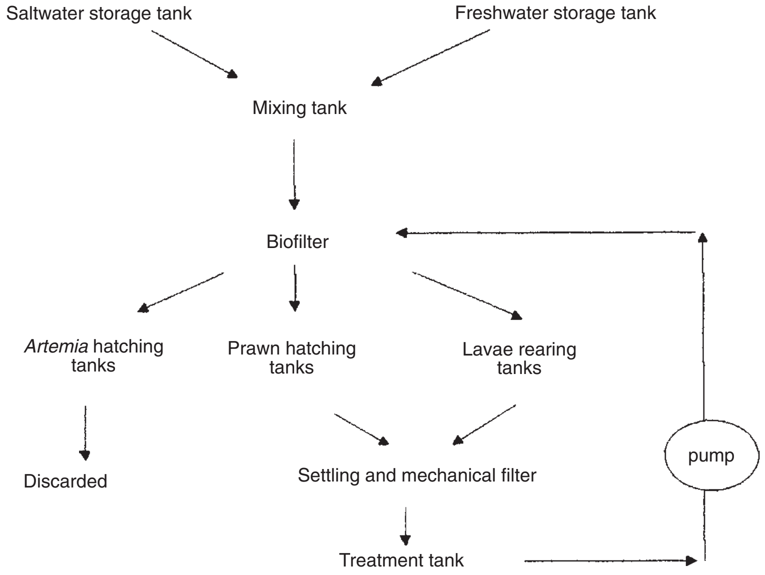


Fig. 6.1 Water flow in a static closed system. (Source: Carvalho & Mathias, 1998.)

Valenti (1996) described various problems associated with static closed systems. These include causing shock to larvae by adding make-up water, peaking of ammonia levels (reaching about 2 mg/L immediately before water exchange), and increasing stress and cannibalism among larvae as density increases during water level reduction. Another problem is that continuous chlorine application can cause excessive chloramine in the system, which is highly toxic to *M. rosenbergii* larvae. Chloramine is a stable compound formed through the reaction of chlorine and ammonia, and is not removed by aeration (Noga 1995). Continuous addition of thiosulphate to de-chlorinate may also lead to stress and mortality since the 'thio'-groups in sodium thiosulphate are used as insecticides to kill other arthropods.

6.1.2 Dynamic closed system

This system is based upon continuous water circulation through mechanical and biological filters, thus providing continuous removal of solid and nitrogen wastes. This assures low levels of ammonia and nitrite and avoids the daily peaks that occur in open and static closed systems. Furthermore, this system does not involve major water replacement, and water quality conditions are stable enough to ensure good conditions for the larvae.

The dynamic closed system used in *M. rosenbergii* hatcheries includes the following components: larval rearing tanks, mechanical and biological filters (biofilters), and, sometimes, disinfection through ultraviolet (UV) lights or ozone (Fig. 6.2). System efficiency is dependent upon filter and tank shape and size, type of biofilter media, and rate and pattern of water circulation, among others. Culture systems can have individual biofilters or one common biofilter for all larval rearing tanks (Valenti *et al.* 1998).

The rate of water recirculation is fundamental for system efficiency. Biomass of nitrifying bacteria present in the biofilter depends on the total amount of ammonia entering the biofilter, instead of its concentration in the water (Brune & Gunther 1981). Therefore, higher flow rate through the filter introduces more ammonia per unit of time and increases the efficiency of the nitrification process (Kaiser & Wheaton 1983). Valenti *et al.* (1998) recommended a high rate of recirculation to reduce the biofilter size. According to these workers, the total water volume in the larval rearing tanks should circulate through the filter 10 to 24 times daily (recirculation rate of 1000–2400% daily). Aquacop (1983) and

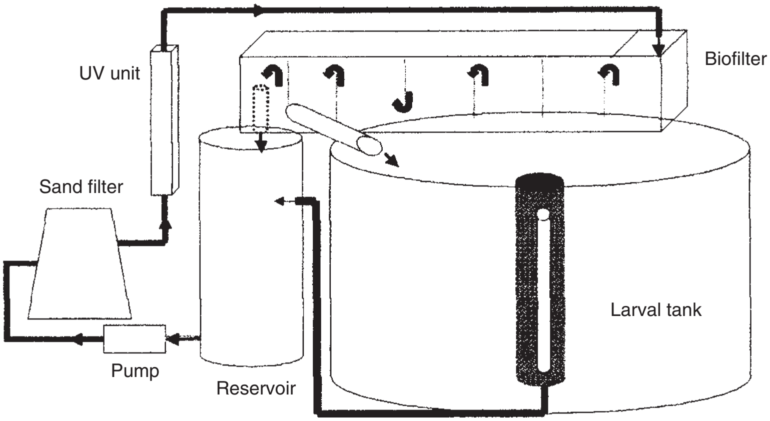


Fig. 6.2 Water flow through basic components of a dynamic closed system

Griessinger *et al.* (1989) developed systems with recirculation rates of approximately 2400 and 1200% daily, respectively. However, many systems often cited in the literature have lower rates, which vary from 140 to 500% daily (Sandifer & Smith 1975; Singholka & Sukapunt 1982; Ong 1983; Castro *et al.* 1988; Chowdhury *et al.* 1993).

In general, dynamic closed systems are believed to be the best systems for *M. rosenbergii* hatcheries. They operate at low cost, have less environmental impact, and provide higher productivity (Valenti *et al.* 1998).

6.2 Facilities

The facility design is based upon the desired rate of production of PL and needs to match the broodstock capacity of the facility. The following example can be used for planning the size of a facility. A 10 000 L tank (10 t) stocked at 50 larvae/L (i.e. 500 000 larvae) with a survival of 80% at the completion of the larval cycle would yield 400 000 PL. To stock this tank would require approximately 25 egg-carrying female prawns averaging 45 g each. This is based upon a healthy 45 g female producing approximately 450 larvae/g. A smaller number of larger prawns would also be effective since larger females will produce more larvae per gram of weight. Fecundity is a linear function of body weight and an exponential function of body length (Malecha 1983). Assuming a desired production of 2 million PL (2.5 million larvae at 80% survival), five larval culture tanks each containing 10 t of water and thus totalling 50 t (50 000 L) would be required.

6.2.1 Physical plant

The physical plant encompasses the entire physical layout of the hatchery facility, including separate rooms for hatching and larval culture tank systems, feed preparation area including live feeds, dry laboratory space, an office, bathroom and auxiliary equipment. An example of a prawn hatchery, the associated infrastructure, and the economics associated with it can be found in Fuller *et al.* (1992). This system is based upon the specifications given for a closed ‘clearwater’ system described in Daniels *et al.* (1992). Although each hatchery differs in size and configuration, commonalties include water preparation tanks, larval culture tanks and biofilters, feed preparation and culture systems, and tanks for spawning and post-larval grow-out. The building needs a back-up generator to operate the pump, air blower, and heaters during any loss of electricity.

The building housing the hatchery facility can be a greenhouse or a more permanent structure. With recirculation systems, excessive solar energy and light produces excessive heat during warmer months and encourages growth of algae, which can foul the tanks and biofilters. When production occurs in a greenhouse, the area above the culture tank should be shaded to provide a good indirect light and the biofilters and live food production areas should be covered completely. In more permanent structures, adequate window area and placement should be made to provide proper lighting, such as presented in the layout by Aquacop (1983) and Valenti *et al*. (1998). Provisions for the availability of intense artificial light as back-up should be included (see also section 6.2.5).

The design of any structure should allow for ease of disinfection to provide adequate larval health management. Normally this includes a concrete floor and walls that are washable. Designs should minimise the amount of outside air (and contaminants) that is drawn through the building's venting system. Large fans in greenhouses, for example, run constantly during warmer months; this tends to draw in outside dust and potentially any agricultural chemicals being sprayed on adjacent areas. Buildings with self-contained heating and cooling systems minimise this risk.

Almost all recirculating systems require water replacement, either daily or to replace water losses. Thus each hatchery system requires additional tanks for water storage and preparation. Efficiently managed systems require less than 10% daily water exchange with additional water needed for live feed culture. If artificial seawater is used, the total volume of water storage tanks can be small but if natural seawater is used it is greater because there needs to be sufficient volume to provide enough brackishwater to fill all rearing tanks and biofilters.

The principal food for prawn larvae is *Artemia* (Chapter 7); therefore, the physical plant must incorporate a system for hatching nauplii and needs to be designed to meet the maximum requirements of the desired level of post-larval production. For example, if 2.5 million larvae have an upper feeding rate of 100 *Artemia*/larvae/day, and assuming an average hatching rate of approximately 150000 *Artemia* nauplii per gram of cysts, then a daily *Artemia* hatch of 1670 g of cysts is required. *Artemia* are generally hatched at 1 to 10 g of cysts/L of water (Sorgeloos 1980). Thus, assuming the use of 1 g of cysts/L of water, the *Artemia* hatchery system would require an 1667 L working volume or about twenty 100 L tanks. Many hatcheries prefer using smaller tanks because of the consistency in production and the ease of harvesting. *Artemia* hatching tanks should be constructed of fibreglass or polyethylene and have a gently sloping, conical bottom equipped with a bottom drain for harvesting and transparent or opaque sides. Additional tanks will be required if fortification of *Artemia* with essential fatty acids or other nutrients is desired (Chapter 7).

6.2.2 Tank designs and accessories

Larval culture systems vary greatly in the size and shape of tanks. Tanks may be oval, cylindrical, or rectangular (with smooth corners), and may have flat, conical, or U-shaped bottoms. They may be constructed of fibreglass, epoxy-painted wood, asbestos or concrete, or some other non-toxic material. The main criteria for choosing the type, shape and size of the culture tanks are the building shape and space available, the timing and number of PL required, and the capacity and the ability to properly circulate and process waste products.

Valenti *et al*. (1998) described the main characteristics of tanks used for recirculation systems. According to these authors, tank size generally varies from 1 to 5 t and the water column should be 0.8 to 1.0 m deep with a freeboard of 0.15 m. The colour of the wall sides and bottom is very important. Lin & Omori (1993) demonstrated that feeding rate decreases with lighter colours. The best survival and food intake occur using black tanks (Lin & Omori 1993; Rodrigues *et al*. 1998). Figure 6.3 shows an overview of rearing tanks operated in a hatchery situated in Argentina. However, at Mississippi State University (Fig. 6.4) the larval rearing tanks used by Daniels *et al*. (1992) were 8 t in capacity; the bottom and the lower 0.3 m of the tank sides were painted beige while the rest of the tank was left black. With the indirect light source, this gave a good colour contrast to *Artemia* and allowed the larvae to feed more efficiently.

One of the most important aspects in choosing the tank design and configuration is proper water circulation to allow adequate removal of waste products (nitrogen and solids) and uneaten feed. Tanks with corners or 'dead spots' (i.e. poor or no water circulation) will trap solids and prevent complete waste removal and proper suspension of food. Therefore, cylindrical (or cylindro-conical) or U-shaped tanks are better. However, most hatcheries use flat-bottomed tanks. Smooth-sided tanks are advisable since rough-textured sides will trap solids and potentially be abrasive to the exoskeleton of larvae, causing injury.

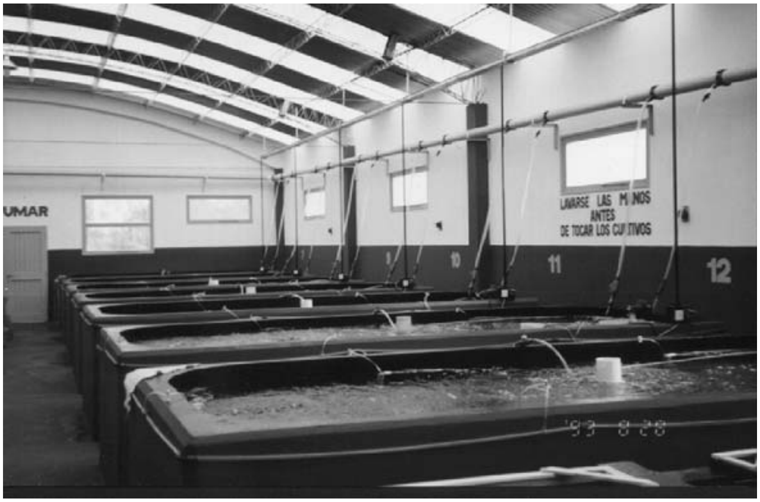


Fig. 6.3 Overview of rearing tanks of the Carblana Hatchery, Argentina. (Source: Carlos Alberto Silva.)

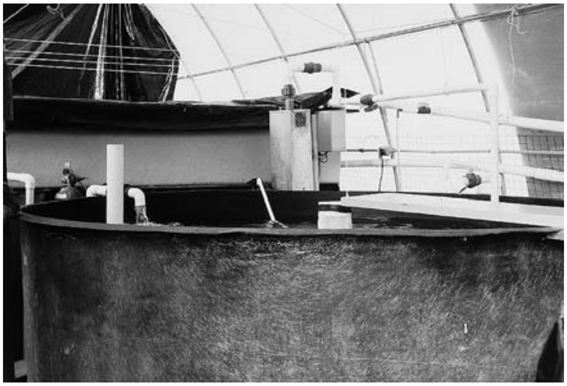


Fig. 6.4 Rearing tanks at Mississippi State University. (Source: William Daniels.)

Improper flow rates or poor circulation within a tank will prevent adequate removal of wastes. As the stocking rate is raised, the turnover rate must be accordingly increased. The highest stocking rates may require a maximum turnover rate of 70 to 100% per hour. A 50 000 L larval culture system requiring a 70% turnover rate would require a flow rate of 35 000 L/h. All pump, filter or disinfecting systems need to match these performance requirements. Water circulation within the culture tank is usually performed using aeration and is such that water circulation is from the centre of the tank to the sides and from the top to the bottom. Failure to provide adequate circulation will lead to 'dead spots' where larvae and feed drop out and are trapped near the tank bottom. Additionally, solid wastes will not be removed from the culture tank to be processed by the filters. Such conditions can lead to excessive build-up of bacteria within the culture tank.

Although a UV light system is an expensive item, its purchase is well worth the expense, especially to the novice. When the water is properly filtered and has good clarity, UV light will kill organisms in the water column. Daniels *et al.* (1992) reported that UV light typically reduced the number of bacteria from a high concentration of 10^6 to 10^9 bacteria/ml (UV inlet) to a low concentration of 1 to 10/ml (outlet). The size of the UV light system depends upon the flow rate. Other types of disinfectant systems may also be applicable to this type of larval system.

6.2.3 Biological filters

Biological filters (biofilters) are used mainly to remove the nitrogen wastes, which come mainly from the ammonia produced by larvae and live feeds (e.g. *Artemia* sp.) during excretion and from the decomposition of organic matter. The nitrogen is converted from ammonia to nitrite and subsequently to nitrate by bacteria through the nitrification process. Spotte (1979), Kaiser & Wheaton (1983) and Brock *et al*. (1994) described the nitrification of ammonia, which results from a sequential action of the nitrifying bacteria. The first group oxidises ammonia to nitrite and is represented by the genera *Nitrosomonas* and *Nitrosococcus*; the second oxidises nitrite to nitrate and includes the genera *Nitrobacter*, *Nitrospina*, *Nitrospira*, and *Nitrococcus* (Brock *et al*. 1994). The nitrification process involves both oxidation and synthesis and consequently results in oxygen consumption and alkalinity destruction (Kaiser & Wheaton 1983).

The type and size of biofilters varies. Many different types of biofilter designs are acceptable, provided they effectively and efficiently remove all ammonia and nitrite produced during the cycle. Valenti *et al*. (1998) described the main types of biofilters which are used in freshwater prawn hatcheries (Fig. 6.5). These authors stated that submerged biofilters are preferred because they are efficient and simpler, and cheaper than others. Chowdhury *et al*. (1993) reported that the submerged biofilters which are horizontally divided into chambers are more efficient. Adequate aeration is necessary to maintain proper dissolved oxygen (DO_2) levels for nitrifying bacteria in submerged biofilters. Griessinger *et al.* (1989) and Daniels *et al.* (1992) utilised biofilters equivalent to approximately 6% of the volume of the larval culture tanks. Biofilter size has varied from 4 to 20% of the rearing tanks (Valenti *et al.* 1998).

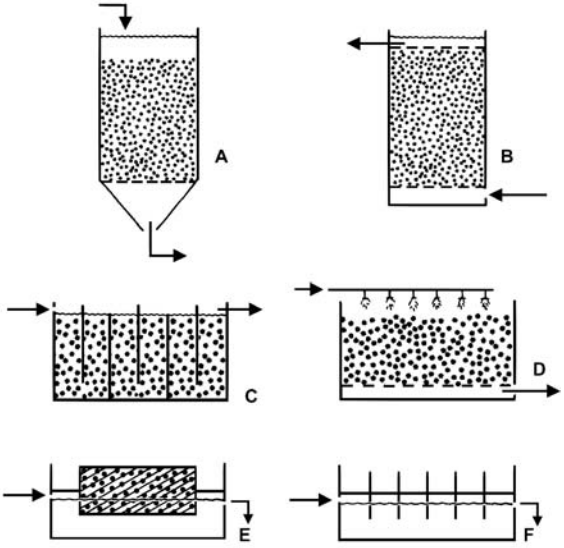


Fig. 6.5 Main types of biofilters used in freshwater prawn hatcheries. (Source: reproduced from Valenti *et al.*, 1998.)

Key: A = submerged downflow; B = submerged upflow; C = submerged horizontal divided into chambers; D = emerged trickling filter; E = biodrum (rotating cylinder containing plastic substrate); F = rotating biological discs.

Typically, some calcareous material is used as the filter medium; smaller particles, such as crushed oyster shell or coral, are recommended. Non-calcareous substances (e.g. plastic beads) can be used but lack the buffering capacity to assist in regulating pH (7.0 to 8.5). If a non-calcareous medium is used, pH may have to be maintained through the addition of chemicals such as bicarbonates. Substrate material can be enclosed in bags fashioned from plastic or nylon netting of the appropriate mesh to facilitate handling.

Biofilters provide media for colonisation by nitrifying bacteria. Biofilters are 'living' systems that must be 'activated', fed, and maintained. Griessinger *et al.* (1989) emphasised the importance of biofilter activation in promoting the growth of beneficial bacteria and in the efficient removal of nitrogenous waste products. Although these bacteria are ubiquitous, inoculation and activation will enhance the efficiency and reduce the start-up time of the filter. When feasible, the biofilter media should be activated in a separate pre-conditioning tank and added to the biofilter as needed to compensate for increases in nitrogenous wastes as feeding and larval biomass increase. This allows the media to be maintained at maximum bacterial loading capacity. Temperature and salinity in the pre-conditioning tank should be stable and equal to conditions in the larval culture tank. The amount of 'activated' substrate in the biofilter at any time should be able to nitrify 100% of the maximum expected ammonia produced by the larvae in 24 h. Griessinger *et al.* (1989) stated that the maximum coral volume, representing less than 4% of the total rearing volume, is reached by day 17 of rearing and a larval stage index (see section 6.4.3) of 8.5.

Many hatcheries do not add 'activated' substrate to their biofilters and yet obtain good production.

However, the use of 'activated' substrate reduces the likelihood of spikes in the level of ammonia or nitrite during the cycle. Procedures for the 'activation' or pre-conditioning of filter media have been described in Daniels *et al.* (1992). The total amount of biofilter media required depends on the daily maximum expected ammonia-nitrogen load in the larval culture system (based on the desired level of post-larval production) and the bacterial carrying capacity of the filter media being used. The filter media carrying capacity is dependent upon several factors including the surface area to volume ratio. Media with a higher surface area to volume ratio will provide more area for bacteria to grow. This area depends mainly on the porosity and diameter of the substrate. Valenti *et al.* (1998) recommended using 5 mm particles of crushed shells. Daniels *et al.* (1992) provided an example for calculating the amount of crushed coral needed to adequately convert the amount of ammonia (60 g of NH_3–N) produced by 2 million prawn larvae in a 24-hour period. This amount was based on empirically derived data of 30 μg/larvae/day. This is equivalent to 226.8 g of ammonium chloride (i.e. 1.0 g of NH_3–N per 3.78 g of ammonium chloride) being completely oxidised by the biofilter media. A bag of well-maintained crushed coral weighing 2.26 kg usually contains a good population of nitrifying bacteria which will nitrify 1 g of ammonium chloride in 24 h (Daniels *et al.* 1992). The required number of bags of crushed coral would, therefore, be 227.

Activation is a step-wise procedure that may begin with an inoculation, using water or media from an existing system, or can start from scratch. Initially, 10% of the required total ammonia is added to the water containing the substrate material in the form of ammonium chloride (NH_4Cl) or another inorganic source. Once this amount is consumed, the same amount is added until that amount can be completely converted to nitrates within a 24-hour period. The amount of ammonia is then doubled until it is completely converted in 1 day. As each level of ammonia is consumed within the desired 24-hour period, the amount is doubled until the maximum required load is consumed daily.

Once the maximum bacterial load is achieved, the production cycle can begin. However, the bacterial population on the media must be maintained at the maximum level of ammonia and nitrite consumption. Addition of media to the biofilter should coincide with the increase of NH_3–N produced by an increase in the larval biomass (Griessinger *et al.* 1989). Typically, beginning 3 days post-stocking, increasing amounts of 'activated' media must be added daily to the biofilter tank. The bacterial population provided through daily addition of media should always be sufficient to remove all ammonia and nitrite. Upon completion of the larval cycle, the biofilter media can be removed, thoroughly rinsed, and either stored dry or returned to the pre-conditioning tank to re-establish and maintain the bacterial colony. Alternatively, the substrate can be chlorinated to kill all bacteria, de-chlorinated, and then re-seeded with stock bacteria from another pre-conditioning tank.

6.2.4 Mechanical filters

Mechanical filters remove the solid wastes produced in the system, which consist mainly of faeces, uneaten feed and bacterial debris. Mechanical filtration may be done in conjunction with the biofilter (e.g. bead filters). Solids are also removed daily during the siphoning of the tank.

The use of decanters and mechanical filters in closed hatcheries was discussed in Valenti *et al.* (1998). Decanters are useful when a single biofilter is used for all tanks. Different types of mechanical filters may be used, but they should be properly sized to match the desired flow rates and the size of solids to be removed. Examples of mechanical filters include sand filters, drum screen filters, and expanded media filters (e.g. bead filters). These may be upflow or downflow designs and should be easily cleaned. Because of the relatively low biomass associated with hatchery systems, sand or bead filters are adequate. Sand filters usually contain a sand particle size of 850 μm. Mechanical filters are typically placed prior to UV light units and biofilters, to maximise their efficiencies.

These filters require flushing on a regular basis (once to several times daily) to prevent any accumulation of organic material which causes clogging, channelling, and growth of potentially pathogenic bacteria. Sand filters may be backwashed with freshwater and air to minimise seawater use. The size of the filter is usually small, relative to the total volume of the system; therefore, the introduction of clean freshwater is normally not a problem.

6.2.5 Light requirements

Light, especially indirect sunlight, is extremely important for freshwater prawn larval culture. Moller (1978) reported that larvae capture food by chance encounter and New & Singholka (1985) stressed the importance of maintaining larval food organisms or particles at densities sufficient to ensure that all larvae have available food in close proximity. However, Daniels *et al.* (1992) reported that prawn larvae do feed by sight as evidenced on cloudy days when feed consumption by larvae is significantly reduced. Larvae normally respond to a decrease in light intensity (e.g. cloudy weather or evening time) by dispersing from the normal 'ring' formed around the inner perimeter of a round tank. Barros & Valenti (1997) observed that while most larvae capture food by chance, some larvae swim in the direction of the food before catching it. These authors postulated that the ability of larvae to detect inert food particles suspended in the water column (or even live food) is a polymorphic characteristic, conditioned by different gene alleles. Aquacop (1977) obtained their best production when larvae were produced in tanks with dark green walls which were located near a window. Those grown in tanks in semi-darkness did not develop beyond stage V. Thus, sufficient light appears to be necessary to ensure maximum food consumption. Indirect natural light produces the best results; direct sunlight may cause mortalities by the apparent sunburning of the exoskeleton and artificial light may have an inappropriate spectral quality (see also Chapter 5). Typical direct natural light intensity on a clear day in the southern USA often exceeds 30 000 lux but indirect light has a much lower intensity. Ang (1996) recommended that a light intensity of at least 6000 lux should be provided for a recirculating hatchery, by means of a transparent roof. However, satisfactory results have been obtained in an indoor hatchery in Brazil with a light intensity of only about 500 lux. Daniels *et al.* (1992) recommended that, for cloudy days and to extend the day length during winter months, intense artificial light should be provided. Although some indication of the importance of spectral quality in an indoor hatchery was seen as long ago as 1970 (New 1990), especially at the near-blue UV wavelength (New 1995), to this day neither the optimum intensity nor its spectral quality have been adequately studied.

6.2.6 Equipment and maintenance

In addition to the equipment already mentioned, numerous other items are required. Fuller *et al.* (1992), Angell (1994) and Valenti *et al.* (1998) provided lists of equipment and their associated costs for designing a hatchery facility. This equipment includes a refrigerator, a stereo microscope, a refractometer, a pH meter, a simple balance, heaters, beakers, glass jars, buckets, several chemicals, etc. Chowdhury *et al.* (1993) described the use of most of them. This equipment is similar to that utilised in other hatchery systems. All equipment needs to be suitable for use in seawater systems and to be free of potential contamination from the leaching of metals such as copper, brass, or zinc. Maintaining equipment, such as pumps, blowers and generators, in good general working condition is critical and, therefore, they should be checked weekly.

6.3 Water source and treatment

When recirculation systems are chosen, the establishment of a hatchery near good-quality freshwater and seawater sources is preferred, but not essential. Closed systems need only about 5% of the water required to operate open systems during the whole production cycle. Water transportation by trucks is economically and technically feasible and frequently used in India (Prakash 1988), Thailand (Menasveta 1991) and Brazil (Valenti 1993a, 1995). Thus, proximity to grow-out farms or suppliers might be more important than water source.

There are few conclusive studies about the effects of water quality on the larval rearing of *M. rosenbergii.* The general issues of water quality are discussed in Chapter 14. With regard to hatcheries, New & Singholka (1985) and Valenti (1985) considered it to be essential to perform a complete chemical analysis of the water before choosing the source. This analysis might show characteristics, such as heavy metals or pesticide contamination, not suitable for aquatic life. Desirable water characteristics for an *M. rosenbergii* hatchery are presented in Chapter 5.

Both freshwater and seawater should be treated before usage. Initially, the water should be filtered to remove suspended solids and parasites or predators, including eggs and larvae. New & Singholka

(1985) described filters suitable for this purpose, including a simple beach filter. Valenti (1996) recommended passing water through a gravel/sand filter to remove larger particles and then through a series of cellulose filters with a porosity of 5 and 2 μm. Subsequently, the water requires disinfection using UV light (Daniels *et al.* 1992), ozone (Valenti 1996; Reddy *et al.* 1997), or chlorine and/or formalin (New & Singholka 1985; Carvalho & Mathias 1998). Some hatcheries use a combination of the above methods. After disinfection, both freshwater and seawater should be stored separately in auxiliary tanks shielded from light to avoid algal growth.

6.3.1 Freshwater

Freshwater can be supplied by either ground or surface water. Municipal water should be avoided because of residual chlorine and the potential of toxic substances from treatment processes and pipes (Valenti 1985). New & Singholka (1985) recommended avoiding surface water, which may be contaminated. Generally, groundwater is free of solids, organics, and pollutants. Therefore, wells often supply the best freshwater for recirculation systems. However, well water may contain toxic levels of some minerals. In intensive agricultural areas, well water should be monitored for high levels of nitrates and phosphorus which result from high nutrient loading.

6.3.2 Natural seawater

Natural seawater can be obtained directly from seawater bodies or seawater wells. Groundwater (well water) is preferred (New & Singholka 1985); however, water analyses should be done to profile the chemical composition and detect any abnormalities or potential toxins (e.g. heavy metals, ammonia). The site requires careful choice to avoid pollution or low salinity during rainy seasons. Hsieh *et al.* (1989) reported lower *M. rosenbergii* postlarval production in Taiwan when polluted seawater was used in hatcheries.

Some inland hatcheries in Thailand, the Philippines and Bangladesh dilute brine or rock salt with freshwater to obtain brackishwater (New 1990; Chowdhury *et al.* 1993). However, ionic composition is not always maintained after the dilution. The use of natural seawater in *M. rosenbergii* hatcheries is preferred because it increases productivity (Daniels *et al.* 1992; Mallasen & Valenti 1998a). The cost is very low for coastal hatcheries. On the other hand, truck transportation costs in Brazil are about US$ 70/m^3 for every 500 km (Silva 1995; Valenti *et al.* 1998); such costs stimulate research into the use of artificial seawater.

6.3.3 Artificial seawater

Artificial seawater has been successfully used in closed system hatcheries. This makes it feasible to set up hatcheries far from coastal areas and close to, or integrated with, grow-out farms. The use of artificial seawater also considerably reduces risks, such as pollution, parasites, and the presence of prawn competitors and predators in larval rearing tanks (Valenti *et al.* 1998). Productivity, using artificial seawater, can be higher than 40 PL/L; however, the cultivation period may be about 10% longer than when natural seawater is used (Mallasen & Valenti 1998a).

Bidwell & Spotte (1985) presented several formulae for artificial seawater preparation. Complete formulation containing all ions is very expensive and non-feasible for commercial hatcheries; suitable formulae containing reduced ion levels need to be species-specific. Thus, the use of artificial salt mixtures is not always successful (Daniels *et al.* 1992; New 1995). Research at Mississippi State University (W. Daniels, unpublished data) suggests that not all commercially available salt formulations are equally efficacious or properly formulated for larval crustacean production. Therefore, caution should be used in selecting one for hatchery production; the formulation should be based on specific research for freshwater prawns. Ions such as: Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, Br^-, HCO_3^-, and possibly SO_4^{2-} are essential for *M. rosenbergii* larval rearing (Zang *et al.* 1995; Mallasen & Valenti 1998b). The Mg^{2+}/Ca^{2+} ratio seems to be important and should be between 1.8 and 2.0 (Zang *et al.* 1995). On the other hand, the ions Al^{3+}, Rb^+, Zn^{2+}, Co^{2+}, Cu^{2+}, Sr^{2+}, Mn^{2+}, HPO_4^{2-}, Li^+, MoO_4^{2-}, and $S_2O_3^{2-}$ may not be essential (Silva 1995; Mallasen & Valenti 1998b). Use of artificial seawater containing only essential ions yields high productivity, but alters larval metabolism from stage V onward, causing an increase in oxygen consumption (Ismael 1998).

Studies aimed at freshwater prawn larval culture using artificial brackishwater have been successful in India (Reddy *et al.* 1991; Nair & Hameed 1992;

Table 6.1 Chemical composition of artificial brackishwater containing only essential ions, used at the UNESP Aquaculture Center (Centro de Aquicultura da Universidade Estadual Paulista – CAUNESP), São Paulo State University, Brazil.

Salt	Quantity (g/m^3 of solution)
Sodium chloride (NaCl)	9200
Magnesium sulphate ($MgSO_4.7H_2O$)	2300
Magnesium chloride ($MgCl_2.6H_2O$)	1800
Calcium chloride ($CaCl_2.2H_2O$)	467
Potassium chloride (KCl)	200
Sodium bicarbonate ($NaHCO_3$)	67
Potassium bromide (KBr)	9

Kanaujia *et al.* 1996) and Brazil (Valenti 1993a; Silva 1995; Mallasen & Valenti 1997, 1998a,b). Commercial production using artificial brackishwater is also being performed in these two countries (Sebastian 1990; Valenti 1993a).

Chemical composition of a simple artificial brackishwater used for the *M. rosenbergii* hatchery at the UNESP Aquaculture Center (Centro de Aquicultura da Universidade Estadual Paulista – CAUNESP), in Brazil, is shown in Table 6.1. The average cost in Brazil is US\$ 75/m^3. The water preparation has been described in detail by Valenti *et al.* (1998). The salts are weighed and diluted individually with previously filtered freshwater. The resulting solutions are added to a tank following the order presented in Table 6.1 and are mixed thoroughly using a PVC stirrer. After that, freshwater is added in order to attain 12 p.p.t. salinity. The final solution is maintained under strong aeration for 24 h and the salinity adjusted, if necessary.

6.4 General management

Hygiene and proper management have fundamental importance for the success of closed system hatcheries. A daily routine should be strictly followed. Any mistake can lead to mortality of larvae. New systems require more accurate monitoring to identify potential problems.

6.4.1 Preparation of the culture system

Daniels *et al.* (1992) described a procedure for preparation of the larval culture system. Initially, the system should be cleaned and flushed with filtered freshwater prior to filling with freshwater (and artificial salts) or seawater. Valenti *et al.* (1998) also recommended that tanks, filters and every piece of equipment should remain immersed in running water for a few weeks prior to first-time use. This process eliminates toxic substances from the material.

If freshwater is used then an artificial marine salt mixture should be added until the desired salinity is achieved. Water prepared using a commercially manufactured artificial salt mixture should be thoroughly filtered after addition of the salts because most of these products use a protein-based carrier molecule that leaves a film or colour. As described in section 6.3.3, caution should be used in selecting artificial salt mixtures and experimentation with new salts is recommended.

After the system is filled and operating, it should be disinfected by adding 5 mg/L of available chlorine a few days prior to stocking. Use of a powdered chlorine product (calcium hypochlorite) is preferred over a liquid product (sodium hypochlorite) since the liquid product is more persistent and not so easily removed by aeration. Aeration and filtration will dissipate most chlorine in a few days. However, the water should still be tested to ensure that no chlorine remains. If chlorine persists, addition of sodium thiosulphate at a concentration of 3 mg/L for each 1 mg/L of chlorine will effectively remove it. Caution should be exercised in the use of sodium thiosulphate because it has been shown to be toxic to penaeid (marine) shrimp larvae (Johnson & Cichra 1985) at low to medium levels (4–50 mg/L). Stage I freshwater prawn larvae have exhibited mortality at levels of 100 mg/L sodium thiosulphate (W. Daniels, unpublished data) and may be stressed at lower levels, too. Alternatively, water may be disinfected using ozone to prevent the problems associated with chlorine and sodium thiosulphate (Valenti 1996).

Salinity and temperature need to be adjusted to optimal larval culture conditions and allowed to stabilise prior to stocking. Systems require adequate heating, and buildings should be properly ventilated to provide a controlled water temperature (28–32°C) regardless of air temperature. Salinity should be kept within 12 to 16 p.p.t. (Sandifer *et al.* 1977; Valenti 1996) and abrupt changes should be avoided. Cooper & Heinen (1991) reported that the best salinity for stage II *M. rosenbergii* larvae is 13 p.p.t. If properly handled and processed, the same brackishwater can be used for two consecutive cycles in *M. rosenbergii* hatcheries without affecting production (Mallasen & Valenti 1998a).

The initial salinity can be made lower (5–7 p.p.t.) than the final salinity used for rearing; this allows larvae to be stocked directly from the hatching tank, without acclimation. The salinity in the culture tank can then be increased by introducing the salt mixture through the sand filter and biofilter tank prior to the addition of any biofilter substrate. Addition of either salts or freshwater to adjust salinity during the larval culture phase should not be performed *via* the biofilter tank once the biofilter substrate has been added. Bacteria in the biofilter are sensitive to sudden changes in temperature and salinity. New water should be disinfected and filtered prior to introduction into the system.

6.4.2 Procurement and stocking of larvae

Newly hatched larvae (stage I) are normally collected from a hatching system but may be harvested from a broodstock holding tank using a collecting device, as described in Chapter 4. Larvae should be healthy and free of debris. Larvae should be enumerated (Chapter 4) prior to transfer to the culture tank. If larvae are hatched in freshwater or low salinity water (0–5 p.p.t.), they should be acclimated to the salinity and temperature of the larval culture system. If acclimation is necessary, a change of 5 p.p.t. or 3°C every 3 to 4 h is recommended. If females are placed into a hatching system, it is recommended that larvae be hatched at 4 to 7 p.p.t. to facilitate acclimation and transfer to the culture system. Collection of larvae for any tank should occur over a maximum of 1 to 3 days to minimise the number of stages present in the culture tank. Collection beyond 3 days may lead to a disparity in growth rates leading to increased cannibalism.

6.4.3 Checking and staging larvae

Larvae should be checked daily to determine the health and developmental stage of the larvae and to control feeding (Aquacop 1983; Daniels *et al.* 1992). Aquacop (1983) recommended observing the colour and swimming and feeding activity of larvae in the tank. They also suggested observing under the microscope the following features: eye surface, antennae, gut content, gill area, pereiopods, pleopods, telson spines, uropod setae, and general pigmentation. It is important to look for necrosis (opaqueness), external bacteria (blackened areas), and missing appendages during observation. Tayamen & Brown (1999) recently developed a simple, objective method to score the condition of *M. rosenbergii* larvae. The method is based upon observation of larvae and scoring them on a condition index using a numerical scale devised by Apgar (1953) to assess the health of human babies. This method has been successfully used in the analysis of commercial hatcheries in Thailand, Malaysia and the Philippines to highlight problems in management (M. Tayamen, in prep.). Using this method, larvae scoring high on this system have been demonstrated to show better growth and survival (M. Tayamen, in prep.). Figure 6.6 and Table 6.2 give details of this assessment technique.

Daniels *et al.* (1992) recommended staging larvae once daily until the first PL appear in the tank. A stereoscope with a range of magnification from 60 to 100× is recommended for staging and checking guts. A microtitre plate may be used to help in examining larvae individually. Ling (1969) and Uno & Kwon (1969) developed criteria to stage *M. rosenbergii* larvae. The latter established that there were 11 larval stages, which are accepted by most authors (Malecha 1983; New & Singholka 1985; Valenti 1985, 1996; Daniels *et al.* 1992). Manzi *et al.* (1977) defined a larval stage index (LSI), which is a calculated weighted average of stage determinations. An example of a stage index is: given 30% (0.3) of the larvae identified as stage 2, 40% (0.4) identified as stage 3, and 30% (0.3) identified as stage 4, then the average stage index is $(0.3 \times 2) + (0.4 \times 3) + (0.3 \times 4) = 3$.

Daniels *et al.* (1992) recommended checking larval gut fullness twice daily after most of the morning and afternoon ration of *Artemia* has been fed. Full guts will appear bright orange (i.e. presence of *Artemia*) and will be pressed against the heart and upper carapace. If guts are not 100% full, then additional *Artemia* should be fed and guts can be re-checked until they become full. Aquacop (1983) stated that food consumption is a good index to estimate larval health. If guts remain less than 100% full for several consecutive days, then a problem is assumed. This problem may be

Explanatory glossary for condition index

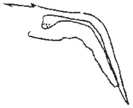
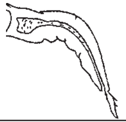
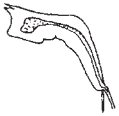
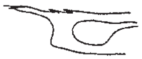
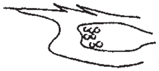
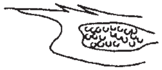
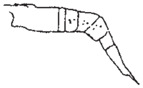
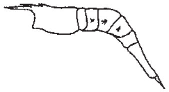
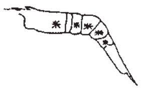
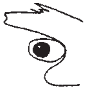
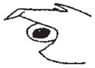
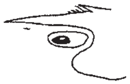
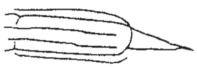
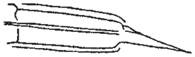
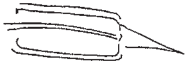
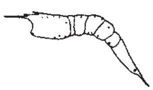
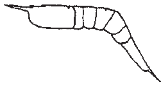
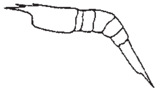
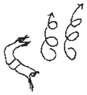
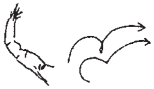
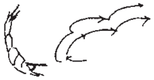
1	GUT FULLNESS	 *GUT EMPTY OF FOOD* Score 0	 *GUT MODERATELY FULL* Score 1	 *FULL GUT WITH FAECAL STRANDS* Score 2
2	GUT LIPID CONTENT (STATE OF HEPATOPANCREAS)	 *LARVAE APPEARS THIN, NO LIPID GLOBULES VISIBLE* Score 0	 *VERY SMALL GLOBULES VISIBLE IN THE DIGESTIVE GLAND* Score 1	 *GLOBULES IN THE DIGESTIVE GLAND VISIBLY FULL* Score 2
3	PIGMENTATION (STATE OF CHROMATOPHORES)	 *FULLY CONTRACTED CHROMATOPHORES ASSOCIATED W/DARK, BLUISH COLOUR* Score 0	 *MODERATE CHROMATOPHORES IN ONE AREA W/LIGHT ORANGE* Score 1	 *WELL DISPERSED CHROMATOPHORES W/AMBER/TAN/RED PIGMENTS* Score 2
4	BODY COLORATION	*GREY/DARK/BLUISH APPEARANCE ON ABDOMINAL SEGMENT* Score 0	*MODERATE LIGHT ORANGE APPEARANCE ON ABDOMINAL SEGMENT* Score 1	*TAN/ORANGE/RED/ AMBER LIKE APPEARANCE ON ABDOMINAL SEGMENT* Score 2
5	SETATION	 *ROSTRUM DAMAGED/ DISFIGURED (Check setae also)* Score 0	 *ROSTRUM CURLED BENT/KINKED (Check setae also)* Score 1	 *ROSTRUM STRAIGHT/WHOLE (Check setae also)* Score 2
6	MUSCLE TO GUT RATIO	 *GUT APPEARS NUDE, MUSCLE THIN IN VI SEGMENT* Score 0	 *GUT APPEARS THIN, MUSCLE IN VI SEGMENT WIDE* Score 1	 *GUT APPEARS THIN, MUSCLE IN VI SEGMENT WIDER* Score 2
7	MUSCLE APPEARANCE OF ABDOMEN (APPEARANCE ABNORMAL MUSCLES)	*ABDOMINAL MUSCLE OPAQUE/GRAINY* Score 0	*ABDOMINAL MUSCLE SLIGHTLY CLEAR* Score 1	*ABDOMINAL MUSCLE CLEAR/TRANSPARENT, SMOOTH* Score 2
8	MELANISATION (PRESENCE OF BLACK SPOTS)	 *BLACK SPOTS SEEN ON APPENDAGES AND/OR BODY* Score 0	 *MINOR BLACK SPOTS ON APPENDAGES/BODY* Score 1	 *NO BLACK SPOTS (MELANIZATION)* Score 2
10a	SWIMMING BEHAVIOUR (BETWEEN STAGE VIII TO X)	 *SLUGGISH MOTION* Score 0	 *MODERATE MOVEMENT* Score 1	 *FAST, JUMP LIKE MOTION* Score 2

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Fig. 6.6 Explanatory pictures concerning the condition index for evaluating larval quality of *Macrobrachium rosenbergii*

Table 6.2 Criteria to determine the condition index for evaluating the larval quality of *Macrobrachium rosenbergii*. (Source: after Tayaman & Brown, 1999.)

	Score*		
Criteria to be checked	0	1	2
Gut fullness	Gut empty	Moderately full (30–60%)	Full gut with faecal strands
Gut lipid content (state of hepatopancreas)	No lipid vacuoles	Very small vacuoles (10–40%)	Relatively full (60–90%)
Pigmentation (state of chromatophores)	No colour pigments (fully contracted chromatophores)	Moderate chromatophores in one area	Well-dispersed chromatophores (pink or amber coloration)
Body coloration	Grey or dark bluish on abdominal segments	Moderate light orange on abdominal segments	Tan/orange/red blend on abdominal segments
Setation	Disfigured or damaged setae on rostrum, pereiopods, telson, uropods	Curled or kinked setae on rostrum, pereiopods, telson, uropods	Straight and whole setae; no deformities on rostrum, pereiopods, pleopods, telson, uropods
Muscle to gut ratio	Gut appears wide, muscle narrower on VI abdominal segment	Gut appears narrow and slightly wider muscle on VI abdominal segment	Gut appears narrow and muscle appears thick and wider on VI abdominal segment
Abdominal muscle appearance (appearance of abnormal muscles)	Opaque/grainy	Slightly transparent	Clear/transparent smooth
Melanisation (presence of black spots)	Appendages and parts of body affected	Very minor necrosis	No necrosis, absence of black spots
Fouling organisms	Major parts of body affected	Minor parts of body affected	Body clean/absence of protozoans, ciliates, organisms
Swimming behaviour (between stage VIII to X)	Sluggish/circular motion, erratic movement	Moderate movement with head upside down	Very active tail first, lateral motion/ jump-like towards the side
Photo positive response (between stage I to VI)	Negative response	Slow positive response	Fast positive response

* Score ratings: 0 = poor; 1 = fair; 2 = excellent.

indicative of stress from poor water quality, disease, or poor feeding.

6.4.4 Water quality

Water requirements for *M. rosenbergii* hatcheries are presented in Chapter 5, while general water quality issues for freshwater prawns are discussed in Chapter 14; however, this section deals with those requiring special management in closed systems.

Dynamic closed systems provide relatively stable water parameters. Salinity normally remains stable during the culture period (Silva 1995; Mallasen & Valenti 1998a) with the exception of water replacement for evaporation and other losses. Because of the relatively low biomass associated with larval systems, DO_2 can be maintained using aeration to satisfy both oxygen and circulation demands. It normally remains constant and above 70% saturation level. Low oxygen concentrations may occur in the biofilter (Daniels *et al.* 1992) and should be corrected to avoid damaging the nitrification process. The temperature should be kept constant (approximately 30°C) by means of heaters.

Water pH is influenced by several processes that occur in closed systems, including nitrification and respiration by prawn larvae, *Artemia* and other aerobic micro-organisms. Generally, biofilter substrates (especially non-calcareous ones) do not buffer pH efficiently (Bower *et al.* 1981). Thus, periodic addition of buffering substances, such as sodium bicarbonate ($NaHCO_3$) and sodium carbonate (Na_2CO_3), may be necessary to maintain pH levels between 7 and 8.5. It has been observed that pH does not vary much during the culture period in closed system hatcheries of *M. rosenbergii* (Aquacop 1983; Valenti 1993b; Silva 1995; Mallasen & Valenti 1998a). This is probably related to the relatively low biomass associated with larval culture and the relatively good buffering capacity of brackishwater.

Dissolved nitrogen compounds (ammonia, nitrite and nitrate) are the most important water quality parameters in closed systems. Monitoring of these compounds indicates biofilter condition and system efficiency. Build-up of ammonia or nitrite indicates that one or both groups of nitrifying bacteria responsible for their conversion to nitrate are present in insufficient numbers, or water quality conditions are not suitable for their growth. The presence of ammonia but little nitrite usually indicates that bacteria represented by the genera *Nitrosomonas* and *Nitrosococcus* are absent, while presence of nitrite but no ammonia indicates the absence of bacteria represented by the genera *Nitrobacter*, *Nitrospira* and *Nitrococcus*. Either condition can be alleviated by addition of more pre-conditioned media.

Ammonia and nitrites can cause severe mortality in *M. rosenbergii* larvae. Sub-lethal concentrations of these two compounds can cause cessation in feeding, retardation of growth, or increased susceptibility to parasites and diseases in prawn larvae (Armstrong *et al.* 1976, 1978). In water, ammonia occurs in two forms, ionised (NH_4^+) and unionised (NH_3). Unionised ammonia increases with increasing temperature and pH (Spotte 1979) and has a higher toxicity. High levels of ammonia in the water also inhibit ammonia excretion by larvae (Regnault 1987). Valenti *et al.* (1998) recommended the maintenance of NH_3-N levels in larval culture below 0.5 mg/L but Lee & Wickins (1992) suggested that they should not exceed 0.1 mg/L, even for grow-out sized prawns. Armstrong *et al.* (1976) recommended maintaining nitrite levels below 1.8 mg/L while Wickins (1982) suggested that the nitrite (NO_2-N) level in grow-out facilities for freshwater prawns should be kept below 1.4 mg/L NO_2-N, a much higher level than those suggested by Lee & Wickins (1992) for penaeid shrimp (<0.2–0.25 mg/L) and tropical (<0.2 mg/L) or temperate (<0.5 mg/L) crayfish. Though scientific evidence is sparse, these authors noted that it is to be expected that larvae will have less tolerance than juvenile or adult prawns. Thus New (1990) recommended that nitrite levels should not be higher than 0.1 mg/L, while Valenti *et al.* (1998) suggested a limit of 0.25 mg/L NO_2-N. However, larvae tolerate levels in the order of 1.0 mg/L, for both ammonia and nitrite (Armstrong *et al.* 1976, 1978; Valenti 1985).

Nitrate (NO_3^-) is stable and accumulates progressively in closed recirculation systems, thus reaching high levels and limiting the use of water. Mallasen & Valenti (1997) established mathematical equations to describe nitrate changes during consecutive cultures using the same water (Fig. 6.7). New (1990) suggested that *M. rosenbergii* larval rearing water should not have nitrate levels higher than 20 mg/L, while Cohen & Ra'anan

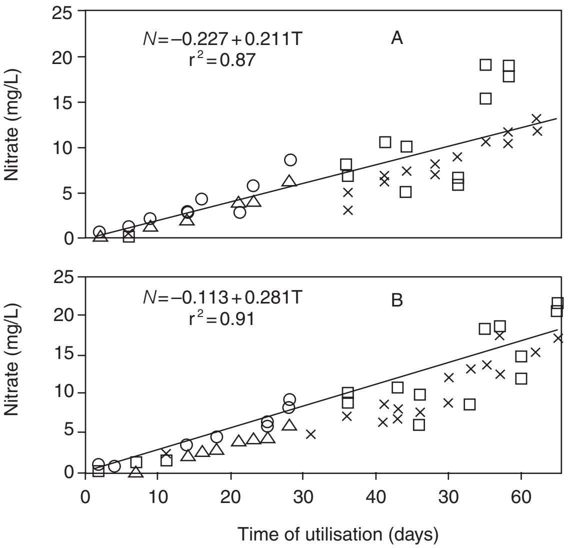

Fig. 6.7 Relationship between nitrate concentration (N) and time (T). (Source: Mallasen & Valenti, 1997.)

Key: A = relationship in natural brackishwater; B = relationship in artificial brackishwater; △ = 1st batch; × = 2nd batch; ○ = 3rd batch; □ = 4th batch.

(1989) stated that larvae tolerate up to 60 mg/L. According to the equation for natural seawater presented in Fig. 6.7, these values would not be exceeded until the third and seventh culture cycles, respectively, when re-using the same water.

From the above review, it is clear that there is disagreement among authors with respect to maximum desirable levels of nitrogen compounds in *M. rosenbergii* hatcheries. There is very little conclusive information about the subject. Data from LC_{50} (lethal concentration for 50% of tested animals during a specific period) or LT_{50} (required time for 50% mortality of animals tested in a determined concentration) has limited application in commercial hatcheries. Studies are necessary to define sub-lethal toxic levels of these compounds and their effects on *M. rosenbergii* larvae.

6.4.5 Feeding strategy

One of the most important aspects of larval culture is the feeding strategy employed. Larvae should neither be overfed nor underfed. Overfeeding results in a build-up of organic material, which causes a proliferation of bacteria and fouling of the water and filtration material. Underfeeding results in poor growth, weak animals, cannibalism, and an extended larval culture cycle. In the vast majority of hatcheries, larvae are fed newly hatched nauplii of *Artemia* and freshly prepared ration (New 1995). However, larval nutritional needs are poorly understood and diets are empirically derived from experimentation; this topic is discussed in Chapter 7.

The establishment of feeding regimes, including feeding schedules and types of feed fed, is extremely important in maximising feeding efficiency. Aquacop (1983), Daniels *et al*. (1992) and Valenti *et al*. (1998) have described feed management in closed systems. These authors disagree on several aspects, as discussed below. However, there is agreement on the use of *Artemia* supplemented with other diets, such as egg custard, and on the quantity of feed being adjusted based upon consumption. Aquacop (1983) and Valenti *et al*. (1998) presented empirical tables, which function as a guide to establishing a feeding programme for larvae in closed systems. However, both papers highlighted the fact that the food quantity consumed by the larvae varies considerably according to culture conditions. Close observation of larvae and monitoring of larval gut fullness and content are the best indicators for determining food consumption and quality.

The timing of feeding and the procedures used vary among hatcheries. Aquacop (1983) and Valenti *et al*. (1998) recommended feeding *Artemia* nauplii only once daily in the late afternoon or evening for nocturnal consumption. Carvalho & Mathias (1998) recommended feeding *Artemia* in the morning and afternoon but only during high-density prestocking of larvae. Daniels *et al*. (1992) proposed that the quantity of *Artemia* supplied should be divided during the day to maximise the nutritional value of nauplii and to avoid waste. These authors made food available to larvae in small quantities from daybreak until sunset by which time guts were normally full. Aquacop (1983) suggested turning off the recirculation system during feeding to avoid *Artemia* leaving the tank. On the other hand, Valenti *et al*. (1998) and Daniels *et al*. (1992) recommended the use of small mesh screens (90–150 μm) to avoid nauplii losses to the biofilter.

Definition of the appropriate amount of food is important since feeding represents a major cost associated with post-larval production (Aquacop 1983; Fuller *et al.* 1992; Silva 1995). Overfeeding increases the labour costs associated with tank cleaning, screen washing, and water quality and larval health management. On the other hand, an excessively rigorous control of feed management might increase labour costs. Generally, the amount of feed supplied increases progressively during the hatchery cycle. However, Barros (1996) found that food ingestion rate varies with larval stage and is not a linear function of development. This results in peaks in food consumption during certain developmental stages and decreases in others.

The larvae of *M. rosenbergii* do not feed during stage I (Ling 1969). Therefore, Aquacop (1983) recommended commencement of feeding the day after stocking, when larvae reach stage II. Despite these observations, New & Singholka (1985) and Valenti *et al.* (1998) recommended feeding on the first day because many larvae moult to stage II during that period. In open flow-through prawn hatchery systems, New & Singholka (1985) recommended that prepared moist feeds (egg-custard based) should be introduced for daytime feeding 3 days after hatching, and that *Artemia* nauplii should be restricted to a single evening dispensation by the fifth rearing day. On the other hand, Barros (1996) reported that less than 50% of the larvae between stages II and VI are capable of utilising either an egg-custard diet or a dry particulate ration. These data indicate that such rations should be given beginning on day 11 or day 12 of cultivation when the majority of the larvae have already attained stage VII. These supplemental feeds must be carefully prepared to provide a highly water stable diet of proper particle size. Use of supplemental feed is believed to compensate for the presumed nutritional deficiencies of an exclusive *Artemia* diet (however, as noted in Chapter 7, some research indicates that *M. rosenbergii* can be reared through all larval stages exclusively on *Artemia*, although enhancement of the nutritional quality of the *Artemia* nauplii improves the results). Feeding supplemental feeds reduces feed costs.

Valenti *et al.* (1998) recommended basing the quantity of *Artemia* fed to the larvae on the tank volume and the previous day's consumption. The concentration should vary from 5 to 15 nauplii/ml immediately after feeding. Aquacop (1983) stated that 5 to 50 nauplii/larva should be supplied daily and according to larval development. New & Singholka (1985) and Valenti *et al.* (1998) recommended that feeding rate should be based on tank volume, not on the number of prawn larvae present, but suggested that 1 to 5/ml/day (depending on larval stage) were required. Daniels *et al.* (1992) followed the recommendations of Aquacop (1983) but found that actual consumption was sometimes twice the 5 to 50 nauplii/larva/day they suggested.

New & Singholka (1985) recommended that prepared feeds (egg-custard diets) could be introduced on the third rearing day in flow-through prawn hatcheries in increasing weaning quantities. By the fifth larval rearing day the prepared feeds can be spread over four to five feeding times per day (in daylight), while *Artemia* are fed once per day in the evening. Aquacop (1983) suggested two daily meals of an egg-custard diet should be provided in a recirculating system given at 08:00 and 12:00 h, beginning on day 10. The daily amount varied between 0.07 and 0.20 mg (dry weight) per larva. This amount provides good guidance but should be adjusted so that there is approximately one food particle per larva (Daniels *et al.* 1992; Valenti *et al.* 1998). This can be estimated using visual observations when the feed is evenly distributed on the water surface. Tank aeration is turned off when doing this. Valenti *et al.* (1998) and Carvalho & Mathias (1998) recommended two or three daily meals. Daniels *et al.* (1992) suggested feeding a prepared feed twice daily (mid to late morning and late afternoon) after larvae have been fed to satiation with *Artemia* starting on day 10. Daniels *et al.* (1992) advised using a screen on the standpipe that is smaller than the food particle size being fed to allow continuous flushing of the culture tank without loss of feed. These authors also recommended determining the appropriate amount of food to be fed by weighing and measuring it volumetrically prior to feeding and then comparing it to the amount of excess feed siphoned during tank cleaning. Little or no food should remain. If food remains then the amount of feed should be reduced.

6.4.6 Daily operations

Daily monitoring of the system's water quality and the larval health and condition are critical for achieving good growth and survival. Failure to be attentive to the needs of the larvae can cause either chronic or acute larval stress. Chronic stress can lead to delayed or improper development of larvae (e.g. 'feathery' PL which exhibit poor survival), poor larval health, and poor survival. Any of these can result in decreased production and increased costs. In closed systems, daily control of the majority of the water quality parameters is not essential because conditions are usually stable. However, the nitrification process should be rigorously monitored. The amount of monitoring is dependent upon the experience of the operational management, its confidence in the system, and the amount of water exchanged daily. Newer systems should be monitored more often to ensure the stability of the system.

Daniels *et al*. (1992) and Valenti *et al*. (1998) supplied step-by-step guides for daily tasks. Morning duties include monitoring both the system and the larvae. Water temperature, flow and level should be monitored and screens cleaned or changed regularly. Water losses should be replaced daily with water properly processed and held in storage. Care should be taken to ensure that water replacement does not shock either the larvae or the biofilter. Mechanical filters should also be monitored and cleaned as needed. Larvae are fed (*Artemia* or prepared diet) and then checked following the steps described in section 6.4.3. *Artemia* nauplii are harvested daily with excess quantities frozen for future use and new cysts are prepared for hatching.

In the afternoon, aeration and water flow should be temporarily turned off and visible waste siphoned in order to avoid increases in organic matter and subsequent increases in heterotrophic bacteria. These are potentially pathogenic bacteria and contribute to additional nitrogen decomposition. Prior to siphoning, the bottom and sides of the tank may also be scrubbed to remove all algae and organic accumulations; however, during the cleaning, aeration must be maintained to prevent larvae from being trapped between the mop and sides or bottom of the tank. Daniels *et al*. (1992) proposed a daily cleaning routine beginning by day 3 and ending after the appearance of PL. Siphoned waste can be used to estimate larval mortality and feeding rates (section 6.4.5). Larvae are again fed and the water temperature checked. Nitrite and ammonia levels should be measured daily until the system is stable, then both should be monitored several times weekly.

Another major concern with any larval system is disease management (Chapter 15), especially monitoring of bacterial populations. Daniels *et al*. (1992) suggested that bacterial concentrations should be monitored several times a week using a dilution method or some other type of testing. However, they emphasised that decreasing food consumption by larvae is an excellent, indirect indicator of bacterial or water quality problems. An experienced manager can use this indicator to identify potential problems and act before a major loss of larvae occurs. Carvalho & Mathias (1998) recommended periodically collecting the scaling from submerged filter and tank walls for microscopic analysis. Baticados *et al*. (1990) evaluated numerous chemicals as controls of *Vibrio harveyi* and *V. splendidus* isolated from diseased *Penaeus monodon* larval culture and concluded that prevention of disease through rigorous water management and sanitation was the best methodology for the control of pathogens. Many of the chemicals used to treat the larvae caused deformities or their use was cost prohibitive.

Health management depends upon cleanliness and minimising the introduction of disease organisms. Every effort should be taken to keep pieces of equipment, supplies, and food clean at all times. Precautions should be taken to prevent the introduction of disease organisms or chemical contaminants by workers and visitors entering the hatchery. Chemical footbaths and washing of hands prior to and when returning to work are recommended (Carvalho & Mathias 1998; Valenti *et al*. 1998). Carvalho & Mathias (1998) recommended cleaning rearing tanks immediately after emptying, disinfecting with 50 mg/L formaldehyde solution, rinsing with clean freshwater, and then drying. All utensils, such as beakers, porous stones, hoses, buckets, etc., should be disinfected every other day using 2.5 mg/L hypochlorite solution, rinsed with freshwater and dried prior to storing.

6.5 Growth, survival and production

Macrobrachium rosenbergii larvae hatch at about 1.9 mm, grow in size to 7.7 mm by stage XI, and then decrease slightly as PL (Uno & Kwon 1969). Generally, growth is measured by the evolution of larval stages. Advancement from one larval stage to the next takes about 2 days until larval stage VII.

Under good growing conditions, the first PL appear on day 19 to 22 (Aquacop 1983). Valenti *et al.* (1998) presented a table containing the typical number of larval stages represented on a daily basis for recirculation systems in Brazil. Malecha (1983) graphically presented similar data from semi-flow through systems (greenwater). The picture is similar until day 15, when development accelerates and becomes more synchronised in recirculation systems. Three to six larval stages may be present in the tank at the same time; however, maintaining three or less will help to minimise cannibalism. The larval rearing period for closed systems generally varies from 30 to 35 days at the optimum temperature (28–30°C) (Aquacop 1983; Ong 1983; Silva 1995; Mallasen & Valenti 1998a; Carvalho & Mathias 1998), but can be less than 25 days (Ra'anan & Cohen 1982).

Daniels *et al.* (1992) suggested that survival during culture can be estimated daily from the number of dead larvae siphoned with debris. This amount is subtracted from the number of estimated larvae in the culture tank on that day to obtain a new estimate. However, cannibalism on dead or weak larvae may reduce the accuracy of this estimation. Usually, this method underestimates mortality but can be a good indicator of increasing mortality and problems. In flow-through systems, New & Singholka (1985) observed that, due to the consumption of dead larvae by the remaining larvae, by the time mortalities are observed the problem is already severe. These authors therefore suggested that if large numbers of mortalities were observed, aborting the larval rearing cycle was better than trying remedial actions. Final survival, given as metamorphosis rate, is generally high for closed systems, being normally in excess of 60% (Ra'anan & Cohen 1982; Ong 1983; Mallasen & Valenti 1998a). Aquacop (1983) and Cohen & Ra'anan (1989) reported average survival rates greater than 75% for large production tanks.

Parseval *et al.* (1989) presented a simulated comparison among different commercial-scale hatchery systems. Estimated average productivity values for greenwater systems (Malecha 1983), as well as open and closed clearwater systems, were 40, 50 and 60–80 PL/L, respectively. Ang (1996) reported the production of 17 to 50 PL/L in a recirculation system. Production for commercial recirculation hatcheries of 60 and 70 PL/L were reported by Aquacop (1983) and Carvalho & Mathias (1998), respectively.

6.6 Harvesting

Daniels *et al.* (1992) recommended several harvests of PL before completion of the production cycle. The first is performed when about 25 to 30% of the larvae have undergone metamorphosis. It occurs, generally, between day 23 and 28. Two or three subsequent harvests are carried out at 3-day intervals until the final harvest. Most authors report only one harvest, when more than 90% of the larvae have undergone metamorphosis (Smith *et al.* 1976; Ra'anan & Cohen 1982; Malecha 1983; New & Singholka 1985; Valenti 1985, 1996; Cohen & Ra'anan 1989; New 1990), despite the potential loss of PL due to cannibalism by larvae. Aquacop (1983) recommended cropping of PL when post-larval density on the bottom of the tank is higher than 2/cm^2.

Aquacop (1983) and Daniels *et al.* (1992) described harvesting methods in recirculation systems. Aeration is discontinued and the water is stirred by hand. Most of the PL cling to the tank side. Larvae are dipped from the tank and transferred to another larval culture tank for continuation of the larval culture or into a temporary tank and then returned to the original tank. Most of the culture water can be pumped out through a small mesh screen into a holding tank for future use. Most commercial hatcheries perform only a final harvest, for economic reasons, and all remaining larvae are discarded. Smith & Hopkins (1977) described an apparatus to separate post-larval prawns and Martinez-Palacios *et al.* (1985) presented a method based on the rheotactic behaviour exhibited by PL. However, both methods are rarely used in commercial hatcheries.

Postlarvae are transferred into another holding tank filled with brackishwater and then acclimated to freshwater over a period of at least 12 h. This is accomplished by diluting the seawater with freshwater of similar temperature. The number of harvested PL can be estimated by counting them in a known volume of water (Aquacop 1983) or weighing the total biomass (Aquacop 1977). Handling and transportation of PL are dealt with in Chapter 5.

6.7 Backyard recirculation hatcheries

In many parts of the world, post-larval *M. rosenbergii* are predominantly produced in backyard hatcheries, particularly in Asia (M. New, pers. comm. 1999). These systems involve cheap and simple structures, use existing farm infrastructure, and are operated using either family labour or cheap labour. The flow-through hatcheries described in Chapter 5 are generally of the backyard type. In Brazil, backyard hatcheries utilising recirculation systems have been proposed as a solution which allows small grow-out farmers to become independent of large commercial hatcheries (Mallasen & Valenti 1996).

Valenti *et al*. (1998) described a backyard recirculation hatchery in detail. This system was developed in Brazil mainly for installation in small grow-out farms. It is basically composed of two 1000 L asbestos or fibreglass tanks connected to a 250 L horizontal biofilter. The larvae hatch in polypropylene boxes or 30 to 50 L buckets. *Artemia* hatch in 20 L plastic bottles reused from discarded materials. Two heaters, a simple scale, and a 0.5 HP blower are the only new equipment to be bought. A freezer, refrigerator, stove and blender are usually already available on the farm. Rearing tanks and the biofilter can be filled with natural or artificial brackishwater. There are no spawning tanks and ovigerous females are obtained directly from grow-out ponds. This system can be set up in a 15 m^2 area with an investment of US$ 4000. Production capacity can reach up to 100 000 PL/month at an operational cost of approximately US$ 400 per cycle.

6.8 References

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7

Larval Prawn Feeds and the Dietary Importance of *Artemia*

Patrick Lavens, Supis Thongrod and Patrick Sorgeloos

This chapter discusses the nature of the feeds necessary for the culture of freshwater prawn larvae. *Artemia* play an essential role as a larval diet in freshwater prawn hatcheries. This chapter therefore pays detailed attention to the supply and processing of *Artemia* cysts. The natural nutritional quality of *Artemia* and its enhancement are also reviewed, before their specific use for feeding freshwater prawn larvae is discussed. Partial alternatives to *Artemia*, both live and inert, are also considered. While the feeding strategies used in research and commercial freshwater prawn hatcheries are detailed in Chapters 5 and 6, the present chapter provides some additional background on this topic.

7.1 Desirable food characteristics

The cultivation of the larvae of *Macrobrachium rosenbergii* is carried out under controlled hatchery conditions, which are quite distinct from grow-out techniques, including feeding strategies. The developing larvae are very small, extremely fragile and remain quite primitive during the early stages using partially developed systems (e.g. digestive organs, eyesight and chemoreception). In addition, larvae have to pass through different developmental stages with distinct properties. Therefore, larvae have limitations with regard to feed intake and digestion, which lead to specific requirements for the type of feed.

Firstly, they have a poorly developed larval gut until larval stage V to VI: i.e. a small hepatopancreas and a lack of the anterior midgut diverticulae (Deru 1990), which are the main sites for digestive enzyme production in the early stages of penaeid shrimp (Lovette & Felder 1990; Abubakr & Jones 1992). Hence, they have a very low trypsin activity and a very low digestive capacity. In contrast to penaeid larvae, they cannot digest artificial diets during that first feeding period and rely on a live food source which is highly digestible and may provide exogenous prey enzymes (Jones *et al.* 1993). More specifically, the live food should be zooplankton since *M. rosenbergii* is carnivorous during the first larval stages; however, from stage VII onwards the larvae become more omnivorous (Barros & Valenti 1997). Food is captured by the thoracic appendages (maxillipeds until stage III, and maxillipeds and pereiopods in stages IV to XI). The capture of food is non-selective but its ingestion is a selective process (Barros & Valenti 1997).

Secondly, the early stages of *M. rosenbergii* are non-active hunters and, although they have a good visual power (Daniels *et al.* 1992), they seem to capture food by chance encounter (Moller 1978). Live preys move continuously in the water column, in this way not only allowing high chances of encounter but also providing an enhanced perception and extra chasing stimulus. Keeping artificial food particles in suspension requires a continuous agitation of the culture medium, which may damage the fragile larvae.

Thirdly, the size of the prey is important. At first feeding (stage II/III), prawn larvae can readily ingest newly hatched *Artemia* nauplii of the Great Salt Lake strain (±500 µm in length). However, the cladoceran *Moina micrura* (±600 µm), which may be used as a cheap substitute or supplement for brine shrimp, is not taken up before stage IV (Alam *et al.* 1995a). On the other hand, Lovette & Felder

(1988) demonstrated that the rotifer *Brachionus plicatilis* (±150 μm), a good zooplankton starter diet for marine fish and penaeid shrimp, is not a good diet for *M. rosenbergii*. An explanation for this observation may be that a larva spends too much effort in capturing sufficient numbers of rotifers to meet its nutritional requirements, and this results in an unfavourable energy balance.

The selection of a proper food source for the industrial production of prawn postlarvae (PL) not only depends on the requirements of the predator. From the practical viewpoint of the culturist, a good diet should be readily and consistently available, cost-effective, and simple as well as versatile in application. The unique property of the branchiopod *Artemia* to form dormant embryos, so-called cysts, may account to a great extent for its designation as a convenient, suitable and excellent larval food source for use not only in freshwater prawn hatcheries but also in those for most other crustaceans and fish. These cysts are harvested in large quantities from natural and semi-natural biotopes and, after processing and drying, are made available in cans as a storable 'on demand' live feed. Upon some 24 h of incubation in seawater, free-swimming nauplii are released and can be directly fed as a nutritious live food source, which makes them the most convenient, least labour-intensive zooplankton available for aquaculture.

For these reasons, *Artemia* have become universally accepted as the live food source in larval freshwater prawn rearing (New 1995). However, once the digestive system of the larva has further developed, allowing a high enzymatic activity (stage IV onwards), this diet is gradually supplemented or substituted with other live foods (e.g. *Moina)*, and by farm-made larval diets or commercially prepared products.

7.2 Supply, preparation and enhancement of brine shrimp (*Artemia*)

7.2.1 Cyst market

Back in the early 1950s the initial commercial sources of cysts originated from the coastal saltworks in the San Francisco Bay (SFB) in California and an inland biotope, the Great Salt Lake (GSL) in Utah. *Artemia* were marketed for the aquarium pet trade at a low price, i.e. less than US$ 10/kg (Bengtson *et al.* 1991). Cyst prices increased considerably in the mid-1970s as the combined result of increased demands from the emerging hatchery activity, decreased harvests from GSL and possibly simulated shortages by certain commercial companies.

At the 1976 Food and Agriculture Organization (FAO) Technical Conference on Aquaculture in Kyoto (Japan) Sorgeloos (1979) launched the idea that the cyst shortage was a temporary problem and could be overcome by the exploration and development of new *Artemia* resources and by the application of improved methods for cyst processing and use. By 1980 the situation had improved with several new commercial products from natural (e.g. Argentina, Australia, Canada, Colombia, France, China) and man-managed (e.g. Brazil, Thailand) *Artemia* production sites. However, cyst quality in terms of hatching rate and nutritional composition proved to be highly variable, not only among the various strains and species of *Artemia*, but also among various batches from the same location (Léger *et al.* 1986). During the 1980s new methods for evaluating and manipulating the hatchability of cysts and the nutritional composition of nauplii were adopted, mainly thanks to the efforts of the research group 'International Study on *Artemia*'. At the same time at the GSL there was an important switch in the harvesting technology applied. *Artemia* were collected from the lake's surface instead of from the shore and together with aeroplane spotting of the cyst streaks, it resulted in a 10-fold increase in yield (>200 t/yr of processed product) and an improved hatching quality. Consequently, there was a dominant presence of GSL cysts on the world market from the mid-1980s onwards. More than 90% of the world's commercial harvest of brine shrimp cysts derived from the GSL and sufficient high hatching product was available to fulfil the needs of the market. Bengtson *et al.* (1991) warned that this development presented a critical situation, since a bad harvest year at the GSL could have a major impact on the provision and price of *Artemia* cysts for the larviculture industry at large.

In the meantime, cyst consumption had increased exponentially as a result of the booming shrimp and fish hatchery industry. In 1997, some 6000 hatcheries required over 1500 t of cysts annually. Approximately 80 to 85% of total *Artemia* cyst sales were destined for shrimp hatcheries; the remaining part mainly went to marine fish larviculture in Europe and East Asia, as well as the pet fish market. Again, the GSL was able to supply that demand by increased harvesting efforts: more companies appeared and more harvesting permits were granted, and very efficient and cost-effective harvesting/processing techniques developed (Lavens & Sorgeloos 1998; Plate 3, facing p. 220). The remaining part (10%) of the world's provision of cysts in the 1990s derived from a number of locations with a limited production or harvesting/processing capacity, mainly natural sites in North and Central China and South Siberia and semi-natural or managed sites in the SFB, South Vietnam, Colombia and Northeast Brazil.

Again, this resulted in a vulnerable situation of dependence on virtually one resource. In an average year the GSL produces about 4000 t of raw, wet cyst material. Processing reduces this raw harvest to approximately 1200 t of processed, commercial product of good hatching quality. However, since the lake is a large natural ecosystem, climatic and other environmental changes may interfere which result in large, often unpredictable, fluctuations in the annual harvests. For example, over the last 10 years the GSL harvest has ranged from 2000 to 6600 t of raw product (Lavens & Sorgeloos 1998). The environmental changes may furthermore influence the dormancy capacity and thus final hatchability of the cysts produced (Lavens & Sorgeloos 1987).

As a consequence, the poor yield from the GSL during the 1994–95 cyst harvesting seasons resulted in a temporary but severe cyst shortage in 1995 (Sorgeloos & Van Stappen 1995). With increasing cyst prices and awareness of the critical situation for the aquaculture industry, several *Artemia* resources were revisited and/or explored with respect to their commercial potential. These resources were situated mainly in Central Asia (i.e. Lake Urmia in Iran) Aibi Lake in China, Bolshoye Yarovoye in Siberia, several lakes in Kazakhstan, Kara Bogaz Gol in Turkmenistan, and salt lakes in Argentina.

The last two harvesting seasons at the GSL (1997/98 and 1998/99) were again poor, resulting in a total yield per harvest year of only one-third of that of the previous two seasons. In addition, the quality of the harvested product was low in 1997/98, resulting in processed cysts of a medium-hatching rate (70%). Moreover, it is expected that this situation will not improve much during the next season(s) since biotope conditions have become rather unfavourable for brine shrimp production. During the 1990s there was a continuous decrease in salinity in the Southern Arm of the GSL. Furthermore, during the period 1998/1999, most likely as a consequence of the 'El Niño' climatic phenomenon, a torrent of freshwater has entered the lake and reduced salinity in most areas below the level favoured by *Artemia*. Such low salinity (i.e. <90 g/L) allows the entrance of predators (e.g. Corixidae beetles, fish), has a negative impact on primary production composition and mode of reproduction of the brine shrimp, and reduces the floating capacity of the fewer cysts produced. An analogous situation happened during the previous big 'El Niño' of 1983, but at that time the Northern Arm of the GSL took over as a cyst-producing site. The latter occurred because culverts and openings through the railroad causeway which divides the lake allowed the influx of large volumes of low salinity water from the Southern Arm, and reduced the salt concentrations in this high-saline biotope to levels acceptable for brine shrimp production. For years, however, these connections have not been maintained and are partially blocked, leading to an almost saturated brine situation (240 g/L) in most parts of the Northern Arm. Although the government is undertaking actions to restore the water flow, it is unlikely that brine concentrations for optimal *Artemia* production in the Northern Arm will recover very quickly.

This situation supports a further intensification of the exploitation of promising natural sites as listed above, and the exploration of new locations in semi-arid areas (Vanhaecke *et al.* 1987; Triantaphyllidis *et al.* 1998). Several of these sources may have a production potential equal to the GSL, as a lot of Asian product is available on the market now. However, it remains difficult to provide good predictions for the future since little information is available on the ecology of these *Artemia* habitats. This means that no stable cyst provisions can be guaranteed, but the diversification of sources will limit the risks of sudden shortages due to environmental changes. In addition, smaller cyst quantities (1–20 t each) of mostly good hatching quality are expected to be provided on a more continuous basis from man-managed ponds and saltworks worldwide (California: A. Schmidt, pers. comm. 1991; Brazil: Camara 1996; Vietnam: Baert *et al*. 1997; Indonesia: E. Kontara, pers. comm. 1995; Chile, Colombia, Eritrea, India, Madagascar, Pakistan, Peru, Thailand: Triantaphyllidis *et al.* 1998 and various personal communications). These small-scale cyst production sites, although technically very successful in several countries in Southeast Asia and Latin America (Sorgeloos 1987), are not expected to contribute significantly to global cyst supplies. Nevertheless, they provide interesting opportunities for local commercial developments, especially in developing countries with import restrictions. In these situations, local cyst availability is an important asset in the development of viable hatcheries.

The latter developments, if well followed-up, may provide several thousands of metric tons of harvestable cysts on an annual basis (Lavens & Sorgeloos 1998). However, it is necessary to stress again that the lack of ecological knowledge for the natural lakes implies that no long-term predictions on productivity can be made. Furthermore, their operation will be cost/market driven, and high productions at the GSL will automatically result in a drop of interest and profitability elsewhere. Also, there are often differences in cysts from alternative locations from the 'classic' GSL product which require attention when applying them in crustacean hatcheries. A few examples may illustrate this:

- deactivation of the dormancy status of Central Asian cysts seems to be difficult, which limits their hatching performance;
- the classical techniques for cyst decapsulation are not applicable with cysts from Central Asia without decreasing their viability, unless some modifications to the protocol are implemented;
- most of the parthenogenetic strains from Asia have a large cyst size;
- little information is available on the nutritional quality of these sources.

Hatchery operators need to have precise information on the origin and characteristics of the cysts which they purchase. It would therefore be desirable for *Artemia* suppliers to provide this information on the cyst products they market, and that no blends of different sources should be processed as has happened in the past. In any case, it will soon be possible to identify the origin of commercial cyst products by means of a DNA-fingerprinting technique recently fine-tuned for application with *Artemia* in Belgium (Sun *et al*. 1999).

The question of the future demand for cysts remains. Again it is difficult to assess annual requirements because a number of factors may interfere. It is difficult to predict the increase in numbers of fry produced by fish, freshwater prawn and marine shrimp hatcheries. Generally, it is expected that hatchery production of marine fish worldwide will further increase (Sorgeloos & Léger 1992), implying a higher need of cysts. Currently (1999), the biggest demand is for penaeid shrimp hatcheries (>80%). The operation of these hatcheries depends in the first place on the requirements of grow-out farms for juveniles. Although the high market prices for shrimp encourage enthusiasm for the expansion of the shrimp business, production increases may not be at the same pace as in the past. They may be limited because of new policies promoting responsible aquaculture, which involve lower stocking densities and less land converted into new ponds. Also disease outbreaks may limit farm operation in certain areas (as happened in Thailand in 1996, for example). Another unpredictable factor is that hatcheries may remain temporarily out of operation when there is an abundant supply of wild seed (e.g. during the 1997 'El Niño' year in Ecuador). On the other hand, cyst shortages encourage the application of modified feeding strategies during the hatchery cycle, reducing the quantities of *Artemia* required.

Artificial diets will certainly gain in popularity in the near future because they reduce the problems and risks involved in the production of live food. Quite a few products are already commercially available for some aquatic species, but their nutritional composition, digestibility and physical performance, especially regarding suspension in the water column and leaching, need to be further optimised before they can completely replace live food in freshwater prawn hatcheries. The application of micro-particulate diets may also depend on the goal which each hatchery seeks to achieve, i.e. the production of high numbers of PL (high densities and survival rates) or the production of high-quality fry (strong, resistant to stress and diseases). The use of formulated diets will be easier in the first case. In any case, it is the cost-effectiveness of the different feeding strategies that will determine the preferential application of inert feed diets or live food organisms. It is likely that this may differ considerably from region to region, and between industrial and backyard hatcheries.

7.2.2 Disinfection, decapsulation and hatching of cysts

Although using *Artemia* cysts appears to be simple, several factors are critical for hatching the quantities needed in larval crustacean production. These include cyst disinfection or decapsulation prior to incubation, and hatching under optimal conditions.

A major problem in the early rearing of prawns is the susceptibility of the larvae to microbial infections. It is recognised that live food can be an important source of potentially pathogenic bacteria, which are easily transferred through the food chain to the predator larvae in commercial hatcheries (Verdonck *et al.* 1994). *Vibrio* sp. constitute the main bacterial flora in *Artemia* cyst hatching media. Most *Vibrio* sp. are opportunistic bacteria which can cause disease/mortality outbreaks in larval rearing, especially when animals are stressed or not reared under optimal conditions. As shown in Fig. 7.1a, *Artemia* cyst shells are loaded with bacteria, protozoa, fungi, and even contaminated with organic impurities. Bacterial contamination in the hatching medium can reach numbers of more than 10^7 CFU/ml (CFU = colony-forming units). At high cyst densities and high incubation temperatures during hatching, bacterial development (e.g. on the released glycerol) can be considerable and hatching solutions may become turbid, which may also result in reduced hatching yields. Therefore, if commercially disinfected cysts are not used, a disinfection procedure consisting of soaking cysts for 30 min in a 2000 mg/L hypochlorite solution (Sorgeloos *et al.* 1986) should be routinely applied. This treatment, however, may not kill all germs present in the alveolar and cortical layer of the outer shell. Recently, a new commercial product of disinfected *Artemia* cysts and modified techniques of application have been introduced, which offer remarkable improvements in live food production (Merchie *et al.* 1997a; Fig. 7.1b).

Complete sterilisation can be achieved through cyst decapsulation. The hard shell which encysts the dormant *Artemia* embryo can be completely removed by short-term exposure to a hypochlorite solution in an alkaline environment and subsequent quenching with thiosulphate (Bruggeman *et al.* 1980; Sorgeloos *et al.* 1986). Decapsulated cysts can be directly hatched into nauplii, or dehydrated in saturated brine and stored for later hatching or for direct feeding. They can be stored in the refrigera-

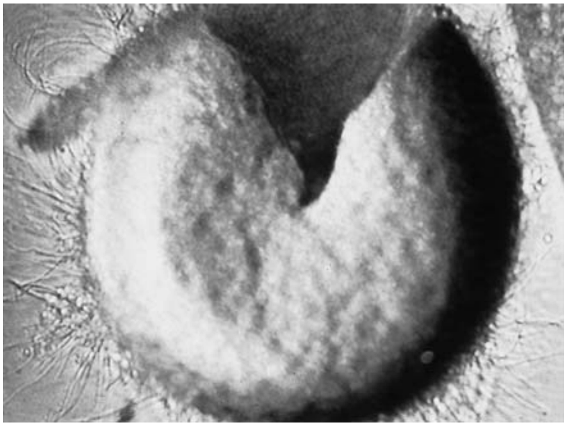

Fig. 7.1a Hatched cyst shell from normal batch of *Artemia* cysts, loaded with bacteria and fungi. (Source: Hatch Controller, Inve Aquaculture, N.V., Belgium; from Merchie *et al.*, 1997a.)

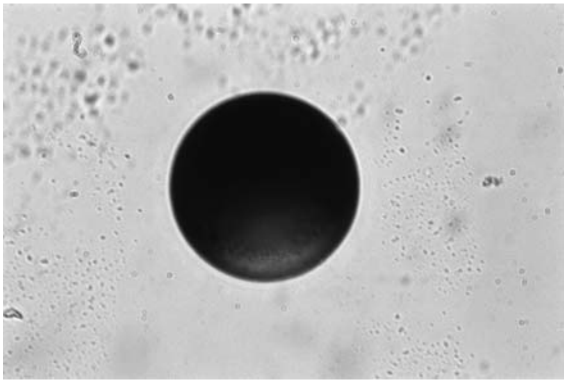

Fig. 7.1b Hatched cyst shell from batch of commercially disinfected *Artemia* cysts. (Source: Hatch Controller, Inve Aquaculture, N.V., Belgium; from Merchie *et al.*, 1997a.)

tor at 0 to 4°C for a few days without any decrease in hatching rate. If storage for prolonged periods is needed (up to a few months), the decapsulated cysts can be transferred into a saturated brine solution. Besides disinfection, decapsulated cysts offer a number of advantages compared to the non-decapsulated ones:

- there is no further need to separate cyst shells from the hatched nauplii, and consequently no more introduction of them into the culture tanks;
- nauplii which are hatched out of decapsulated cysts have a higher energy content and individual weight (30–55%, depending on strain) than regular freshly-hatched larvae, because they do not expend the energy which is necessary to break out of the shell. In some cases, where cysts have a relatively low energy content, the hatchability may be improved by decapsulation, because of the lower energy requirement to break out of a decapsulated cyst (Vanhaecke *et al.* 1983).

Although hatching of small quantities of *Artemia* cysts is basically very simple, several parameters need to be taken into consideration for the successful hatching of kilogram quantities of cysts that is a daily practice in large hatcheries: aeration, temperature, salinity, pH, cyst density and illumination. The best hatching results are achieved in cylindrical containers with a conical bottom, aerated from the bottom with air lines. Flat-bottomed tanks have dead spots in which *Artemia* cysts and nauplii accumulate and suffer from oxygen depletion. Transparent or translucent containers facilitate inspection of the hatching suspension, especially when harvesting.

As a consequence of specific characteristics, the interactions of the hatching parameters may be slightly different from strain to strain, resulting in variable hatching results. The aeration intensity must be sufficient to maintain oxygen levels above 2 mg/L, preferably 5 mg/L. The optimal aeration rate is a function of tank size and the density of cysts incubated. Excessive foaming can be reduced by disinfection of the cysts prior to hatching incubation and/or by addition of a few drops of a non-toxic antifoam agent (e.g. silicone antifoam). The temperature of the seawater is preferably kept in the range of 25 to 28°C; below 25°C cysts hatch more slowly and above 33°C cyst metabolism is irreversibly stopped. Optimal hatching salinity is within the range 5 to 35 g/L; above a threshold salinity of approximately 85 to 90 g/L insufficient quantities of water can be taken up by the cysts to allow full hatching metabolism. For reasons of practical convenience natural seawater is mostly used to hatch cysts. At 5 g/L salinity, however, the nauplii hatch faster, as less glycerol has to be built up. For some sources of cysts, hatching the cysts at low salinity results in higher hatching efficiencies and the nauplii have a higher energy content.

The pH must remain above 8 during the hatching process in order to ensure optimal functioning of the hatching enzyme. If needed (e.g. when low salinity water is used), it is necessary to increase the buffer capacity of the water by adding up to 1 g $NaHCO_3$/L. Increased buffer capacities can also become essential when high densities of cysts are hatched (= high CO_2 production). Strong illumination (about 2000 lux at the water surface) is important, at least during the first hours after complete hydration, in order to trigger the start of embryonic development. Although this level of illumination is mostly attained in daytime in transparent tanks which are set up outdoors in the shade, it is advisable to keep the hatching tanks indoors and to provide artificial illumination, in order to ensure good standardisation of the hatching process. Cyst density interferes with the other abiotic factors which are essential for hatching, i.e. pH, oxygen, and illumination. The density may be as high as 5 g/L for small volumes (<20 L) but should be decreased to a maximum of 2 g/L for larger volumes, to minimise mechanical injury of the nauplii and to avoid suboptimal water conditions.

All these factors affect the hatching rate and maximum output, and hence the production cost of the harvested *Artemia* nauplii. Considerable variation has been demonstrated among commercial products of various origin, and even among batches from the same site, which obviously accounts for much of the price differences. Therefore, attention should be paid to selecting *Artemia* cyst lots with good hatching synchrony (less than 7 h between hatching of first and last nauplii), fast hatching rate (less than 24 h), and high hatching efficiency (more than 200 000 nauplii per gram of product) (Fig. 7.2). When hatching synchrony is low, first-hatched nauplii will have consumed much of their energy reserves by the time that the last nauplii will have

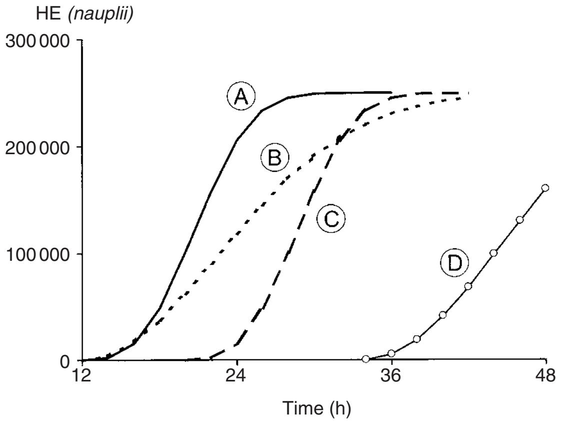

Fig. 7.2 Examples of the hatching rate of A: good and B: less good *Artemia* cyst batches and rates of appearance of C: the second and D: the third instar stage in the hatching/enrichment tank for cyst batch A

hatched and harvesting is done. If the total incubation period exceeds 24 h the hatchery operator is unable to restock the same hatching containers for the next day's harvest, which implies higher infrastructural costs.

After hatching, and prior to feeding them to the larvae, *Artemia* nauplii need to be separated from the hatching wastes. After switching off the aeration in the hatching tank, cyst shells will float and nauplii will concentrate at the tank's bottom. They should be siphoned off within 5 to 10 min and thoroughly rinsed with seawater or freshwater, preferably using submerged filters (Sorgeloos & Léger 1992) to prevent physical damage to the nauplii.

7.2.3 Use of nauplii and metanauplii

In their first stage of development, *Artemia* nauplii do not feed but consume their own energy reserves (Benijts *et al.* 1976). At the high water temperatures that are applied during cyst incubation, freshly hatched *Artemia* nauplii develop into the second larval stage within 6 to 8 h. It is important to feed first-instar nauplii rather than starved second-instar metanauplii which are transparent and less visible. Second instar metanauplii are about 50% larger in length and swim faster than first instars. As a result they are less acceptable as prey. Furthermore, they contain lower amounts of free amino acids so they are less digestible and their lower individual dry weights (DW) (1.63 µg *versus* 2.15 µg in the SFB strain) and energy content (0.0366 J *versus* 0.0500 J in the same strain) reduce the energy uptake by the predator per unit of hunting effort (Léger *et al.* 1986). All this will be reflected in reduced larval growth in the face of increased *Artemia* cyst consumption: 20 to 30% more cysts are needed to feed the same weight of starved metanauplii to the freshwater prawn larvae. On the other hand, second instar stages may be more susceptible to digestive enzyme breakdown in the gut of the predator since these enzymes can also penetrate the digestive tract of the *Artemia* through the open mouth or anus.

Storing freshly hatched nauplii at temperatures near 4°C, in densities of up to 8 million nauplii per litre for up to 24 h greatly reduces their metabolic rate, and precludes moulting to the second instar stage (Léger *et al.* 1983). The drop in individual DW at 4°C is only 2.5% *versus* 30% at 25°C. The 24-hour cold storage technique economises *Artemia* cyst hatching effort (e.g. fewer tanks, larger volumes, a maximum of one hatching and harvest per day) and not only allows a constant supply of a high-quality product but also the possibility of more frequent food distributions. This is beneficial for prawn larvae because food retention time in larviculture tanks can be reduced and hence the growth of *Artemia* in the culture tank minimised. With poor hunters, such as the early larval stages of *M. rosenbergii*, feeding cold-stored (and thus less active) *Artemia* results in a more efficient food uptake.

7.2.4 Nutritional features

The nutritional effectiveness of any food organism is in the first place determined by its ingestibility and, as a consequence, by its size and form. Naupliar size, varying greatly from one geographical source of *Artemia* to another, is often not critical for crustacean larvae, which can capture and tear apart food particles with their feeding appendages. As long as prey size does not interfere with the ingestion mechanism of the predator, the use of larger nauplii (with a higher individual energy content) will be beneficial since the predator will spend less energy in taking up a smaller number of larger nauplii to fulfil its energetic requirements.

For *M. rosenbergii* this means that, even at first feeding, a GSL type of *Artemia* can be used.

Another important dietary characteristic of *Artemia* nauplii was identified in the late 1970s and early 1980s, when many fish and shrimp hatcheries scaled up their production and reported unexpected problems when switching from one source of *Artemia* to another. Japanese, American and European researchers studied these problems and soon confirmed variations in nutritional value when using different geographical sources of *Artemia* for shrimp, prawn, lobster and crab species (Léger *et al.* 1986). The situation became more critical when very significant differences in production yields were obtained with distinct batches of the same geographical origin of *Artemia*. Studies in Japan and the multidisciplinary 'International Study on *Artemia*' revealed that the concentration of the essential fatty acid 20:5 n-3 (eicosapentaenoic acid, EPA) in *Artemia* nauplii was determining its nutritional value for larvae of various marine fishes and crustaceans (Léger *et al.* 1986). Various results were obtained with different batches of the same geographical *Artemia* source, containing different amounts of EPA and yielding proportional results in growth and survival of mysid shrimps (*Mysidopsis bahia*) fed these *Artemia* (Léger *et al*. 1985). Levels of this essential fatty acid vary tremendously from strain to strain and even from batch to batch, the causal factor being the fluctuations in biochemical composition of the primary producers available to the adult population (Lavens *et al.* 1989). In addition, another even more important essential fatty acid for brackishwater larval organisms, docosahexaenoic acid (DHA: 22:6 n-3; Watanabe 1993), is almost lacking in *Artemia*. In contrast to freshwater species, most marine organisms do not have the capacity to biosynthesise these essential fatty acids from lower unsaturated fatty acids, e.g. 18:3 n-3, and this nutrient needs to be provided through the food chain. In view of these fatty acid deficiencies in *Artemia*, appropriate techniques have been developed for improving the lipid profile of deficient *Artemia* strains (see section 7.2.5).

According to recent findings (Helland *et al.* 2000), and in contrast to an earlier study by Seidel *et al.* (1980), the content and pool composition of free amino acids (FAA) in *Artemia* nauplii also varies significantly both within and among brine shrimp species. Parthenogenetic *Artemia* seem to contain three times more FAA than the GSL strain. However, essential amino acids are generally present in sufficient quantities in *Artemia* nauplii. It is possible that methionine (Dabrowski & Rusiecki 1983), or leucine (Conceiçao 1998) are the first-limiting amino acids.

The presence of several proteolytic enzymes in developing *Artemia* embryos and *Artemia* nauplii (Garcia-Ortega *et al.* 1998) has led to the speculation that these exogenous enzymes play a significant role in the breakdown of the *Artemia* nauplii in the digestive tract of the predator larvae. This has become an important question, in view of the relatively low levels of digestive enzymes in many first-feeding larvae and the inferiority of prepared feeds *versus* live prey.

The levels of several minerals in *Artemia*, as reported in the literature, have been summarised by Léger *et al.* (1986). The mineral requirements of marine organisms are poorly known but may be met by the seawater that they drink. A recent study of the variability of 18 minerals and trace elements in *Artemia* cysts revealed that the levels of selenium in some cases may not be present in sufficient quantity (Merchie 1996).

Vitamin C, more specifically ascorbic acid (AA), is generally considered to be an essential dietary component for larval stages of aquaculture organisms, and is involved in several biological as well as physiological functions (Dabrowski 1992; Merchie *et al*. 1997b). Ascorbic acid 2-sulphate (AAS), a stable derivative of AA, is the storage form in dormant cysts of *Artemia*, but batches from various origins may differ considerably in AAS content, ranging from 160 to 517 µg/g DW, expressed as AA (Dabrowski 1991; Merchie *et al*. 1995a). The amount of the active AA form, liberated in the nauplii during hatching (300–550 µg/g DW), reflects the AAS reserve present in the cysts (Dabrowski 1991; Nelis *et al*. 1994). The variation in AAS concentration observed in *Artemia* cysts may reflect adult nutrition during egg production, as was demonstrated in the case of the highly unsaturated fatty acid (HUFA) content (Lavens *et al*. 1989), and this may explain the differences among batches of the same strain (Merchie *et al*. 1995a). Vitamin E (α-tocopherol) concentrations in freshly hatched nauplii vary slightly among different strains, i.e. between 99 and 124 µg/g DW (Huo *et al*. 1996). San Francisco Bay *Artemia* cysts were analysed for the content of various other vitamins and were found to contain high levels of thiamine (7–13 µg/g), niacin (68–108 µg/g), riboflavin (15–23 µg/g), pantothenic acid (56–72 µg/g) and retinol (10–48 µg/g) (Stultz 1974). Published data indicate that the levels of vitamins in *Artemia* are sufficient to fulfil the dietary content recommended for growing fish. However, requirements during larviculture are still mostly unknown, and may be higher due to a higher rate of larval growth and metabolism (see also section 7.2.5).

7.2.5 Enrichment

Taking advantage of the primitive feeding characteristics of *Artemia* nauplii, it is possible to manipulate the nutritional value of deficient *Artemia*, e.g. HUFA deficiency in the GSL strain. Since brine shrimp nauplii that have moulted into the second instar stage (i.e. about 8 h following hatching) are non-selective particle feeders, simple methods have been developed to incorporate different kinds of products (HUFA, vitamins, drugs) into the *Artemia* prior to feeding to predator larvae. This method of bio-encapsulation (Fig. 7.3), also called *Artemia* enrichment or boosting, is widely applied in marine fish and crustacean hatcheries for enhancing the nutritional value of *Artemia* with essential fatty acids. British, Japanese and Belgian researchers developed enrichment products and procedures using selected micro-algae and/or micro-encapsulated products (Wickins 1972), omega-yeast and/or emulsified preparations (Watanabe *et al.* 1982), and self-emulsifying concentrates and/or micro-particulate products (Léger *et al.* 1987). Besides the enrichment diet used, the techniques employed vary with respect to pre-enrichment time (time between hatching and addition of enrichment diet), enrichment period, and temperature.

The highest enrichment levels are obtained from emulsified concentrates (Léger *et al.* 1986). Freshly hatched nauplii are transferred to the enrichment tank at a density of 100 to 300 nauplii/ml (for enrichment periods >24 h or <24 h, respectively). Nauplii should be transferred or exposed to the enrichment medium as soon as possible before first feeding so that they begin feeding immediately after the opening of the alimentary tract (second instar stage; Fig. 7.2). As a result, the increase in nauplius size during enrichment can be minimised. After 24-hour enrichment GSL nauplii will reach about 870 µm, and after 48-hour enrichment about 1010 µm (Fig. 7.4). The enrichment medium consists of hypochlorite-disinfected and neutralised seawater maintained at 25 to 28°C. The enrichment emulsion is added in consecutive doses of 0.3 g/L every 12 h. Strong aeration using air stones or pure oxygen is required to maintain dissolved oxygen

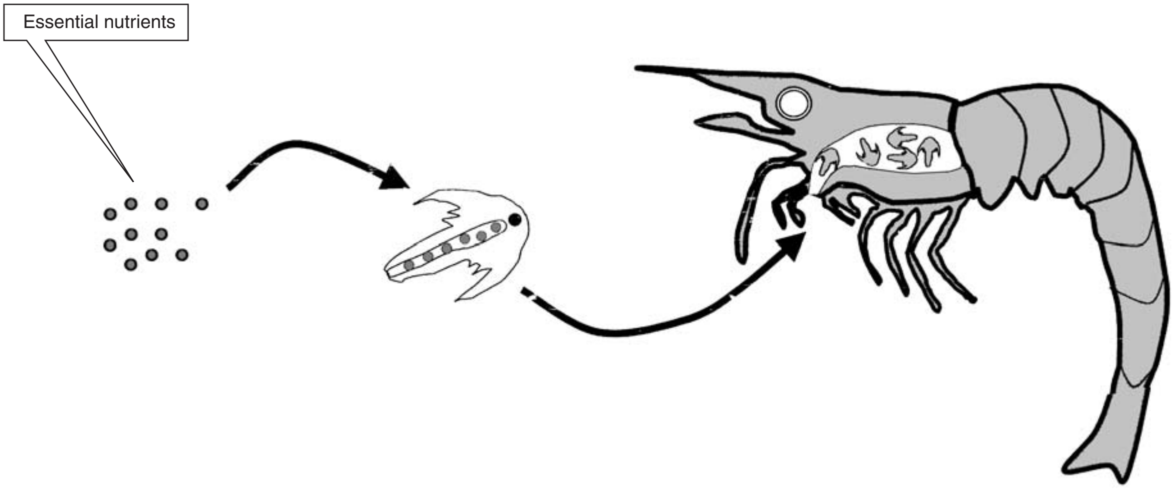

Fig. 7.3 Schematic diagram of the use of *Artemia* as a vector for transfer of specific nutrients to marine shrimp larvae

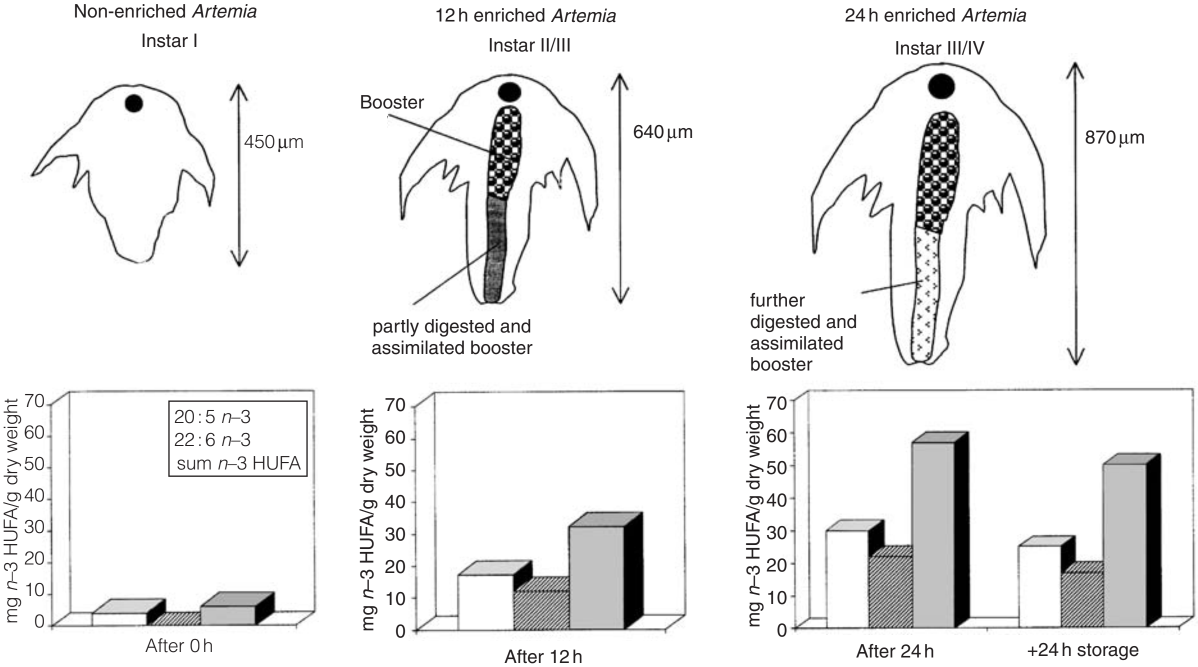

Fig. 7.4 Highly unsaturated fatty acid (HUFA) levels in GSL *Artemia* metanauplii enriched with Super Selco (Inve Aquaculture, Belgium) for 12 and 24 h and subsequently stored for 24 h at 10°C. (Source: modified from Merchie, 1996.) Histogram key: no shading, 20 : 5*n*–3; cross-hatching, 22 : 6*n*–3; shaded grey, sum *n*–3 HUFA.

levels above 4 p.p.m. Enriched nauplii are harvested after 12 or 24 h and thoroughly rinsed using analogous procedures as after hatching (Léger *et al.* 1987). They are directly fed or stored at temperatures below 10°C at densities up to 5000/ml in order to ensure that HUFA are only slowly metabolised during storage, i.e. a reduction of 0 to 30% after 24 h at 10°C (Fig. 7.4). Enrichment levels of 50 to 60 mg/g DW n-3 HUFA are obtained after 24-hour enrichment with the emulsified concentrates, which are well above the maximal concentrations found in natural strains. However, it should be indicated that studies have demonstrated a large variability in enrichment levels even when applying a standard boosting procedure (Lavens *et al.* 1995). Feeding n-3 HUFA-enriched *Artemia* nauplii results in increased larval survival and growth in *M. rosenbergii* as well as in several *Penaeus* spp. (Bengtson *et al.* 1991).

In view of the importance of DHA in marine species much effort is made to incorporate high levels of DHA and high ratios of DHA/EPA in live food. So far, best results have been obtained with special enrichment emulsions fortified in DHA (containing a DHA/EPA ratio up to 7) yielding *Artemia* metanauplii that contain 33 mg DHA/g DW. Compared to enrichment with traditional products, a maximum DHA/EPA ratio of 2 (instead of 0.75) can be reached under standard enrichment practices. The reason for not attaining the same ratio in *Artemia* as in the enrichment products is the inherent catabolism of DHA upon enrichment in the most commonly used species of *Artemia*. The capability of some specific Chinese *Artemia* strains to reach high DHA levels during enrichment and to maintain them during subsequent starvation (Evjemo *et al.* 1997) may open new perspectives to provide higher dietary DHA levels and DHA/EPA ratios to crustacean larvae, if required.

In addition to essential fatty acids, other nutrients such as vitamins and pigments can be incorporated in *Artemia.* Recently, experiments have been conducted to incorporate ascorbic acid in live food. Using the standard enrichment procedure and experimental self-emulsifying concentrates containing ascorbyl palmitate (AP) in addition to the fish oils, high levels of free ascorbic acid (AA) can be incorporated into brine shrimp nauplii. As shown by Merchie *et al.* (1997a), a 10% AP inclusion (on a DW basis) in the emulsion enhances by 50% the natural levels occurring in freshly hatched nauplii (500 µg/g DW), while a 20 or 30% addition increases AA levels in *Artemia* respectively three-fold and six-fold after 24-hour enrichment at 27°C; HUFA levels remain equal compared to normal enrichment procedures. Moreover, these AA concentrations do not fall when the enriched nauplii are kept in the rearing tanks for 24 h or cold-stored at 4°C. In the same way, vitamin E (α-tocopherol) levels can be boosted from 100 to 1000 µg/g DW (Huo *et al.* 1996) and vitamin A from 1 to 1200 IU/g DW (Dedi *et al.* 1995) in brine shrimp metanauplii.

The incidence of microbial diseases has increased dramatically along with the degree of intensification in the larval production of aquaculture species. Treating microbial infections in fish and crustacean larvae most frequently involves dissolving relatively high doses of broad-spectrum antibiotics in the culture water. A disadvantage of this method is the large amounts of expensive drugs that are used and discharged into the environment, thus endangering animal and human health. A direct treatment through the food chain (oral administration) using much smaller quantities has proven more effective and safer for the environment. In this respect the possibility to load *Artemia* nauplii with doses up to 300 µg/g DW of the therapeutic mixture Trimetoprim : sulphamethoxazole (1 : 5), using self-emulsifying concentrates containing 10% of the mixture, and incorporation in predator tissues has been demonstrated (Verpraet *et al.* 1992; Robles *et al.* 1998).

Except for the need to provide *Artemia* under the most hygienic form (see section 7.2.2), as freshwater prawn larvae were considered sensitive to infections, it was originally expected that freshwater prawn larvae would not have specific nutritional requirements in terms of this food source. In contrast to penaeid shrimp, the (n-3) HUFA requirements of *M. rosenbergii* were not expected to be very critical, in view of the fact that they spend most of their life in freshwater. Roustaian *et al.* (1999) also concluded that the larvae of *M. rosenbergii* have sufficient capability to convert dietary linoleic acid (18 : 2 n-6) and linolenic acid (18 : 3 n-3) to arachidonic acid (20 : 4 n-6) and EPA to meet larval demand for HUFA, although there was no assimilation and consequent tissue storage of DHA. As a result it was claimed that non-enriched *Artemia* can fulfil the nutritional requirements providing the greenwater system is used. These assumptions, however, are in some way contradicted by studies at the Artemia Reference Center of Ghent University, where *M. rosenbergii* larvae were reared on *Artemia* alone in a clearwater circulatory system. Devresse *et al.* (1990) demonstrated that pronounced improvements were obtained in growth, survival, metamorphosis synchrony, and stress resistance when *Artemia* enriched with n-3 HUFA emulsions were administered (Fig. 7.5). The levels of these essential fatty acids (EFA) in the larval tissue also increased as a function of the dietary regime, as also demonstrated by Roustaian *et al.* (1999). This fatty acid requirement was further confirmed by Romdhane *et al.* (1995), who documented a minimum requirement of 35 mg/g n-3 HUFA in the freshwater prawn diet throughout the larval cycle or at least during the first weeks of larval culture. However, de Caluwe *et al.* (1995) demonstrated that these EFA effects in larval prawn are also a function of the broodstock diet. Larvae obtained from *M. rosenbergii* females fed a HUFA-fortified diet performed equally well on non-enriched as on enriched brine shrimp.

Feeding vitamin C-enriched *Artemia* does not result in an enhanced freshwater prawn hatchery output (Merchie *et al.* 1995b). However, a significantly positive effect was again demonstrated on the physiological condition of the PL, as measured by a salinity stress test. A noticeable drop in the vitamin C level of PL, compared to larvae, indicated a need for ascorbic acid during metamorphosis, a stressful period (Table 7.1). It is likely that under suboptimal rearing conditions (stress situations) high vitamin C supplementation will enhance production characteristics.

Recently, the same research group in Ghent developed a standardised technique based on ammonia toxicity for the evaluation of (post-)larval quality of hatchery-produced *M. rosenbergii* which is far more sensitive than the salinity stress test. Using this criterion, they were able to clearly demonstrate that, from larval stage III onwards, larval quality was superior in the prawn culture tanks receiving HUFA/vitamin C-enriched *Artemia*

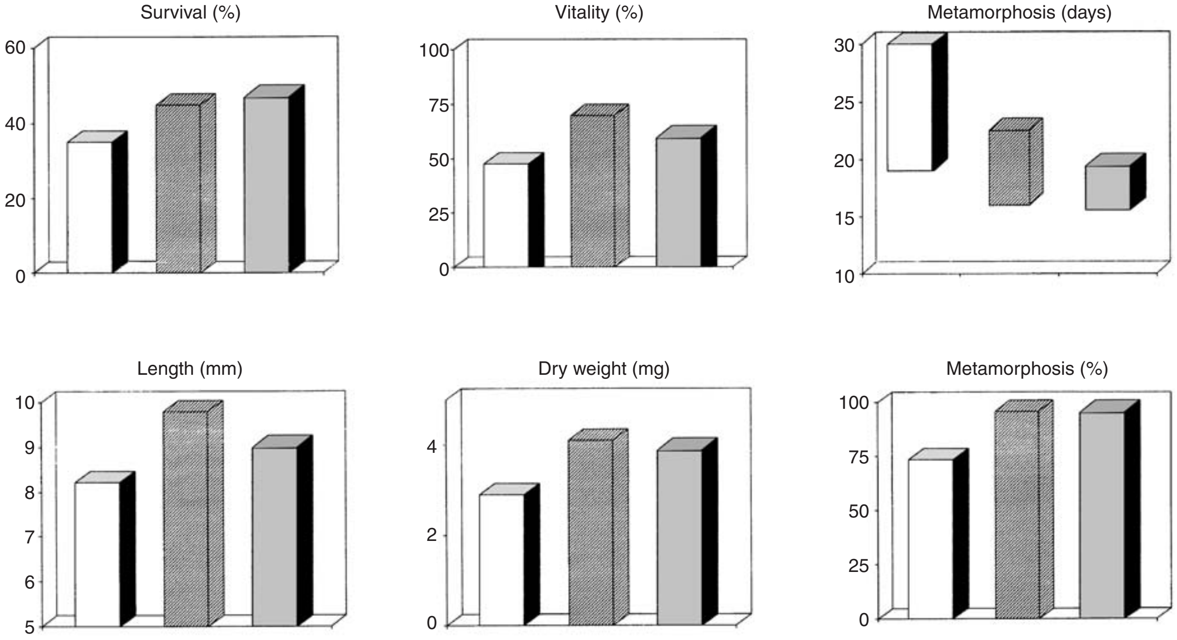

Fig. 7.5 Production characteristics of *Macrobrachium rosenbergii* larvae fed *Artemia* nauplii enriched with low (open bar), medium (hatched bar) and high (dark bar) levels of highly unsaturated fatty acid (HUFA). (Source: modified from Merchie, 1996.)

Table 7.1 Effect of vitamin C enrichment in *Artemia* nauplii on the larviculture success of *Macrobrachium rosenbergii* until day 28. (Source: Merchie *et al.*, 1995b.)

	Level of dietary ascorbic acid (µg/g)		
	650	1300	2600
Survival (%)	58	58	57
Individual length (mm)	9.67	9.73	9.58
Individual DW (µg)	1130	1200	1310
Metamorphosis (%)	41	53	49
Survival after osmotic stress (%)	40	62	74
Larval ascorbic acid content (µg/g DW)	352	448	507
Ascorbic acid in postlarvae (µg/g DW)	255	389	432

DW = dry weight.

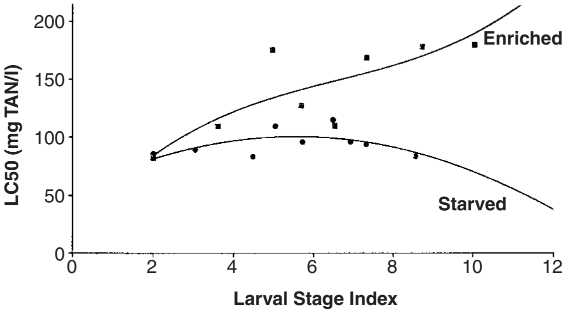

Fig. 7.6 Polynomial regressions of the estimated 24-hour LC_{50} values for total ammonia nitrogen (TAN) as a function of the larval stage index of *Macrobrachium rosenbergii* larvae fed either enriched or starved *Artemia*, demonstrating the difference in quality between the two cultures of larvae. (Source: modified from Cavalli *et al.*, 2000.)

compared to the cultures fed the non-enriched brine shrimp (Cavalli *et al.* 2000; Fig. 7.6).

In view of the research findings reviewed above it is suggested that commercial freshwater prawn hatcheries would benefit from the use of enriched *Artemia* throughout the culture period, unless other HUFA- and vitamin-rich supplements are administered from stage V onwards.

7.3 Other larval feeds

7.3.1 Non-*Artemia* live feeds

Moina is occasionally used as a non-*Artemia* live feed in the larviculture of freshwater prawns. Whereas *Artemia* is an Anostracan, *Moina* belongs to the suborder Cladocera, which are small crustaceans that almost exclusively live in freshwater. A thick carapace encloses the whole trunk, except the head, and there is also a saddle ridge on the posterior part of the body; both may thus interfere with the digestibility by predators. *Moina* thrives in freshwater ponds and reservoirs but primarily inhabits temporary ponds or ditches. The period to reach reproductive maturity takes 4 to 5 days at 26°C. Females are bigger than males (1.0–1.5 *versus* 0.6–0.9 mm) and carry only two eggs enclosed in an ephippium which is part of the dorsal exoskeleton. *Moina* can also be mass cultured using various waste products as a food source (Punia 1988; Shim 1988), and produced biomass has been successfully used in the larviculture of several fish species and the giant freshwater prawn. The nutritional composition of *Moina* depends on the diet administered, but is generally high in proteins and low in n-3 HUFA. Enrichment can be carried out using the direct method, i.e. by culturing them on baker's yeast in combination with emulsified marine oils. Experiments have shown that *Moina* takes up n-3 HUFA in the same way, although slower, than *Artemia* nauplii, reaching a maximum concentration of 40% after a 24-hour feeding period (Delbare & Dhert 1996).

Generally, most freshwater prawn hatcheries prefer *Artemia* over *Moina* as a live food source because of its higher nutritional value and digestibility, its better availability, and because it thrives well in brackishwater conditions. *Moina* does not tolerate saltwater and survives only for 5 to 10 min in 12 g/L salinity water (Tattanon & Ruangpanit 1978). The dead *Moina* sink to the bottom of the tank where they become unavailable for the prawn larvae and, hence, their decomposition results in deterioration of the rearing water quality. They can, however, be adapted to salinities up to 7 g/L (Aniello & Singh 1980) and S. Pitipornchai & B. Nuang-saeng (pers. comm. 1999) report maximal survival for 4 to 6 h at that salinity.

Direct replacement of *Artemia* by *Moina micrura* without affecting production conditions for *M. rosenbergii* is only possible from stage VI onwards: earlier stages apparently have low ingestion rates of *Moina*, which may be related to the difficulty in capturing and ingesting the relatively large live prey (Alam *et al.* 1995a). This confirms earlier findings of Alam *et al.* (1993a) who reported high mortalities in prawn larvae fed *Moina* during the first 7 days of culture. Nevertheless, S. Pitipornchai & B. Nuang-saeng (pers. comm. 1999) report that in Thai commercial hatcheries, even at a reduced salinity of 6 to 8 p.p.t. and after a 1-week *Artemia* feeding period, the substitution by *Moina* still resulted in a 20% lower post-larval survival, i.e. 40 to 60%. Alam *et al.* (1993b) suggested that the n-3 HUFA composition of *Moina* affected the larviculture output. A good tool to overcome this problem could be the addition of marine oils to the egg custard that is co-fed during the day time to the prawn larvae (Alam *et al.* 1995b).

7.3.2 Inert feeds

Although *Artemia* (especially when enriched) allow for the successful hatchery culture of freshwater prawn larvae (Devresse *et al.* 1990; Merchie *et al.* 1995b; Romdhane *et al.* 1995), various attempts have been made since the 1970s to either supplement or substitute this live food with other diets during its life cycle. The main incentives for this are the high cost and inconsistent supply of cysts, the need for extra infrastructure for hatching and enrichment, and the potential for introducing pathogens into the culture tanks. On the other hand, Daniels *et al.* (1992), Valenti *et al.* (1998) and Pitipornchai (1998) stated that *Artemia* nauplii do not provide all of the nutritional requirements of *M. rosenbergii* for late larval stages and that it is necessary to supplement the diet with an inert feed. Fish flesh was very commonly used as a supplement at the start of freshwater prawn hatchery activity in Hawaii, Asia and South America (Malecha 1983; New & Singholka 1985; Valenti 1985). Nowadays, most hatcheries use a simple farm-made feed for this purpose. Minamizawa & Morizane (1970) and Murai & Andrews (1978) successfully supplemented newly hatched brine shrimp with chopped fish and short-necked clam, and freeze-dried oyster meat, respectively. However, such natural products have a number of negative aspects that limit their use in intensive hatchery systems: e.g. highly variable size of the particles, variable quality, high leaching rates and consequently a detrimental influence on culture water quality. Therefore, the focus for substitution products should be on formulated (artificial) diets, which do not have these negative characteristics.

Artificial diets have not been found to be so successful for prawn larval rearing as with marine shrimp. Exclusive replacement with microencapsulated diets (MED) throughout the larval cycle has not been effective, although Deru (1990) demonstrated that *M. rosenbergii* larvae could survive on MED from zoea VI–VII to metamorphosis. Ohs *et al.* (1998) evaluated a spray-dried artificial diet for prawns and also found that the survival and growth rates of larvae were poor when larvae were fed exclusively on the artificial diet. Bell (1994) postulated that the problem was not one of nutritional inadequacy in the MED but rather a lack of assimilation capacity of the early larval stages. Unlike penaeid shrimp, first-feeding freshwater prawn larvae do not have anterior midgut diverticulae, which are the main sites for digestive enzyme production during the early stages in marine shrimp (Lovette & Felder 1990; Abubakr & Jones 1992). The hepatopancreas of freshwater prawns is also relatively small during early larval stages. A considerable increase in trypsin activity levels coincides with the expansion of the hepatopancreas after stage V (Jones *et al.* 1993), when they are able to survive on artificial diets (Deru 1990). On the other hand, Kamarudin (1992) found that the amylase levels in the herbivorous protozoeal stages of *Penaeus (Marsupenaeus) japonicus* were much higher than the levels observed in the early stages of carnivorous shrimp larvae. A specific amylase content in *M. rosenbergii* larvae can only be observed from stages VII–VIII onwards, suggesting that from then onwards prawn larvae are less exclusively carnivorous (Kamarudin *et al.* 1994). In other words, they may have specific nutritional requirements during the first-feeding period.

Extra problems could be related to ingestion and gut retention time. Deru (1990) found that early stages of *M. rosenbergii* larvae rapidly accept and consume microcapsules; however, Kumlu (1995) demonstrated that after a short period of consumption, the microcapsule is totally rejected by the larvae. Sick & Millikin (1983) examined the effect of adding selected attractants to a porous gel diet for *M. rosenbergii* consisting of fish, soybean, and shrimp meals. These workers found that the addition of ovalbumin, in combination with certain amino acids (proline, arginine, glycine, taurine), resulted in significantly increased ingestion rates by all larval stages. Prawn larvae do not actively capture their prey, and the ability of larvae to catch sufficient food is reliant on the chances of encounter. Buoyancy as well as water stability are therefore important particle characteristics. Jones *et al.* (1993) reported that the herbivorous larval feeding strategy employing a short gut retention time and low assimilation efficiency relies on a fast turnover to balance metabolic requirements and hence is well adapted to utilise artificial diets, which are relatively indigestible. In contrast, *M. rosenbergii* larvae have a long gut retention time to extract maximum energy from ingested prey. Diets should therefore be highly digestible, providing energy in a form that can be most efficiently used. However, at present the knowledge of specific nutritional requirements of prawn larvae is not well documented (see Chapter 13).

In commercial hatcheries, both 'backyard' and large-scale, hatchery managers are applying many types of supplemental food in addition to *Artemia*. In some cases, this practice has improved the survival and metamorphosis of prawn larvae (Pitipornchai 1998). The success of such techniques not only relies on the high nutritive value of the feed, but also on the standard of rearing management. Nevertheless, most prawn hatcheries rely on using simple farm-made feeds in combination with *Artemia* nauplii.

Farm-made larval feeds in Thailand originate from the work of Chacheongsao Fisheries station, which received United Nations Development Programme (UNDP)/FAO assistance during the late 1970s and early 1980s (Boonyaratpalin & New 1993). These feeds (Table 7.2) basically consist of egg custard, made from a mixture of whole eggs and full-fat milk powder. Milk powder (2 scoops or 9 g) is first stirred in 200 ml of hot water. Six chicken eggs are added and the whole portion is then homogenised in a blender and steamed for at least 20 minutes or until cooked. Sometimes a vitamin premix is added. An important factor in the satis-

Table 7.2 Composition and nutritive value of egg-custard feeds for *Macrobrachium rosenbergii* larvae in Indonesia and Thailand.

	Quantity	
Ingredients	*	**
Fish meal	100 g	–
Skimmed milk	250 g	9 g
Duck egg	10 pieces	–
Chicken egg	–	6 pieces
Freshwater	250 ml	300 ml
Wheat flour	250 g	–
Vitamin C	5 tablets	–
Vitamin A + D	50 drops	–
Vitamin B complex	5 tablets	–
Tetracycline	5 capsules	–
Calcidol	10 ml	–
Proximate analyses	% dry matter	
Protein	22.8	44.4
Fat	4.5	39.4
Carbohydrate	49.0	8.2
Fibre	5.7	–
Ash	3.3	3.8
Moisture	14.7	4.2

* Adisukresno *et al*. (1982).
** Tunsutapanich *et al*. (1984); Pitipornchai (1998).

factory preparation of this feed is the warming-up of the container in which the ingredients are mixed, because this results in a softer feed which is preferred by the prawn larvae (A. Tunsutapanich, pers. comm. 1999). Fish, crab, squid and mollusc meat, which are ground and sieved to a particle size of 300 to 500 µm, are sometimes added to these egg custards. The cooked custard is broken up into small particles through a series of fine sieves, according to the size of larvae. Corbin *et al*. (1983) and New & Singholka (1985) recommended that inert feed particles of about 0.3 mm should be used up to rearing day 10 to 12; from then until metamorphosis, particles gradually increasing up to 1.0 mm were suitable. Sick & Millikin (1983) reported that porous, pliable gels cut into 3 mm cubes were readily acceptable to all larval sizes. In Brazil, the optimal range of feed particles for various larval stages are stated to be 0.2–0.4, 0.4–0.7 and 0.7–1.0 mm for larval stages IV–VI, VII–VIII and IX–PL, respectively (Correia & Castro 1998). The graded particles are then collected and stored in a refrigerator. In practice this farm-made feed is freshly prepared every 2 days (Tunsutapanich *et al.* 1984; Pitipornchai 1998). The egg custard is administered during daytime only, during which time the quantity of *Artemia* nauplii gradually declines until the evening, when new nauplii are added. In Thailand, after metamorphosis occurs, the PL are normally fed with a 100% custard diet, of which a portion of the eggs is substituted by fish, crab, squid and/or mollusc meats previously ground and sieved to a size of 300 to 500 µm.

Alam *et al*. (1995b) describe an egg custard enriched with cod liver oil, which was used in conjunction with *Moina micrura* for feeding freshwater prawn larvae. From rearing day 10 onwards, in a recirculation hatchery, Daniels *et al.* (1992) used a supplemental diet, consisting of 85% cleaned squid, 10% chicken eggs, 3% beef liver powder, and 2% cod liver oil bound with an alginate hardened by $CaCl_2$. This feed was sieved through 250, 425, 600, 850 and 1000 µm sieves before use. Nair & Hameed (1992) described the use of a coagulated suspension of 1 kg of 'thelly' (*Metapenaeus dobsonii*) meat mixed with 10 hens eggs in commercial freshwater prawn larval rearing in India. After blending and coagulation by gentle cooking, this feed was sieved to produce 200 to 400 µm particles for larval stages up to IV, 400 to 600 µm for stages V–VIII and 600 to 1000 µm for stages IX–XI. This feed was supplied with a daily (evening) supply of *Artemia* at 3 to 5 nauplii/ml. The formula for an egg-custard diet used in some Brazilian freshwater prawn hatcheries is given in Table 7.3. Another, micro-particulate diet, also used in some hatcheries in Brazil (P. Castro, pers. comm. to E. Correia, 1998) is given in Table 7.4. It is certain that many variants of inert feeds are used in freshwater prawn hatcheries; probably there are as many variants as hatchery managers!

7.4 Feeding strategies

Newly hatched *M. rosenbergii* larvae are around 2 to 2.2 mm in length. They normally start feeding about 1 day after hatching and initially require live zooplankton. Their prey should be of a suitable size for ingestion; the optimal size is estimated at 300 to 500 µm. Newly hatched *Artemia* nauplii are considered the most successful starter diet but, after the

Table 7.3 Composition and nutritive value of egg-custard feeds for *Macrobrachium rosenbergii* larvae used in Brazil. (Source: Mallasen & Valenti (1998); Valenti *et al.* (1998).)

Ingredients	Wet weight %
Chicken egg	34.0
Squid flesh	10.0
Fish flesh	10.0
Dried milk	4.0
Wheat flour	2.0
Fish liver oil	0.8
Vitamin mix	0.7
Mineral mix	0.7
Water	37.8
Total	100.0
Proximate analysis	**Dry weight %**
Crude protein	45.07
Crude fat	22.55
Fibre	–
NFE	23.55
Ash	8.83
Total	100.00
Gross energy (kcal/kg)	4989.20

NFE = non-fibrous extractives.

Table 7.4 Formula for micro-encapsulated diet for freshwater prawn larvae in Brazil.

Quantity	Ingredient
800 g	Squid
2	Chicken eggs (white and yolk)
30 ml	Cod liver oil
1 tablespoon	Mineral salts
1 capsule	Vitamins A/D/E
250 mg	Sodium alginate
0.5 g	Calcium chloride
1000 ml	Water (12 p.p.t.)

first rearing week, are usually fed in combination with prepared diets.

Sick & Beaty (1975) maintained an *Artemia* density of 0.1 nauplii/ml in an early experiment on inert feeds for freshwater prawn larvae. However, New & Singholka (1985) pointed out that they did not actively seek food and recommended the maintenance of 1 to 5 nauplii/ml, depending on the size of the prawn larvae. Furthermore these authors suggested that the level in the rearing water should never fall below 1 nauplius/ml to ensure maximal encounter possibilities. This practice is commonplace in Thailand but 5 to 15 nauplii/ml were used in Hawaiian hatcheries (New 1990). Many failures in early freshwater prawn hatcheries were associated with inadequate supplies of feed because hatchery operators did not realise the essentiality of providing food organisms close to the prawn larvae (M. New, pers. comm. 1999) Feeding rates up to 100 nauplii per prawn larva by day 15 (= approximately 5 nauplii/ml) were applied by Daniels *et al.* (1992). Ingestion rates of live food for the various larval stages of freshwater prawns were reported by Alam *et al.* (1995a; Fig. 7.7). Ensuring that *Artemia* are available throughout the day, to avoid either over- or under-feeding, is essential. Energy intake in *M. rosenbergii* is directly proportional not only to *Artemia* concentration but also to *Artemia* size. Sick & Beaty (1975) demonstrated that stage VII–VIII prawns attained a maximum energy ingestion of 0.0066, 0.062 and 1.014 cal/mg animal DW/h, respectively, when fed 0.7, 1.5 or 5.5 mm brine shrimp. As highlighted in section 7.2.5, it is furthermore recommended that *Artemia* nauplii should be enriched with HUFA/vitamin C-fortified products to enhance their nutritional composition prior to their administration to the prawn hatchery tanks.

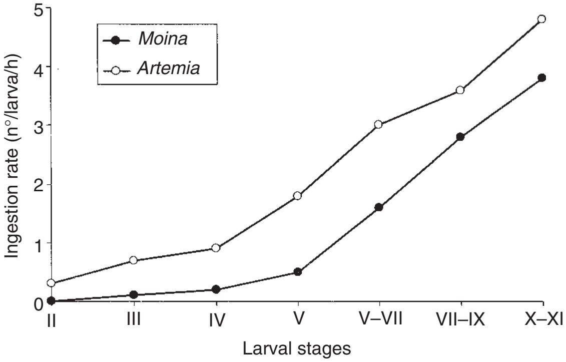

Fig. 7.7 Ingestion rates of *Macrobrachium rosenbergii* larvae feeding on *Artemia* nauplii and *Moina micrura*. (Source: modified from Alam *et al.*, 1995a.)

Although 'greenwater' culture systems, designed to enhance the availability of natural food organisms through fertilisation, as well as to improve rearing water quality, were in favour in many freshwater prawn hatcheries in the 1970s (New 1990), almost all small and large hatcheries operate on 'clearwater' systems because they are easier to manage (New 1995). Some exceptions were noted in the early 1990s in Malaysia (Brown 1991) and Mauritius (Thompson *et al.* 1992). The rearing water of commercial hatcheries therefore currently has minimal inherent nutritional value; the larvae are almost entirely dependent on the live food and inert feeds that the hatchery operators supply. Several investigators have discussed the potential role of unicellular algae in the successful culture of *Macrobrachium* sp. However, the cause and effect relationship between the algae and larval nutrition has never been established. Maddox & Manzi (1976) studied the effects of seven species of unicellular algae on rates of survival and metamorphosis and concluded that all algal species enhanced the successful culture of larvae, with the diatom *Phaeodactylum tricornutum* as the most effective species. On the other hand, Sick & Beaty (1975) could not demonstrate a nutritional effect of phytoplankton added to larval culture systems, while Joseph (1977) was not able to detect any fatty acid assimilation from algal populations in *M. rosenbergii* rearing tanks. Cohen *et al.* (1976) confirmed that *M. rosenbergii* larvae did not ingest ^{14}C-tagged algae. Also, enzymatic studies showed that first-feeding prawn larvae are carnivorous rather than herbivorous (Jones *et al.* 1993). Thus the contribution of unicellular algae may be rather a 'greenwater' effect than a nutritional one (i.e. they assist in maintaining acceptable water quality conditions, antibiotic activity, etc.).

In order to economise on hatchery feed costs, *Artemia* nauplii may be supplemented with *Moina* sp. The use of farm-made larval feeds is commonplace and some freshwater prawn hatcheries use commercially prepared larval feeds. Aquacop (1983), Daniels *et al.* (1992) and Valenti *et al.* (1998) suggested the use of brine shrimp nauplii as a sole food up to day 10 to 12 for maximal hatchery output. After that, the use of an inert feed as a supplement to, or a total substitute for, *Artemia* is applied for cost-effective reasons, and without affecting survival and growth, in the larval culture of *M. rosenbergii*. Alam *et al.* (1995a) claim that a complete replacement of brine shrimp by *Moina micrura*, a cheap live food source, is possible from stage V onwards, without affecting growth or survival of the prawn larvae. This has, however, not been confirmed in commercial operations in Thailand, where a 20% lower post-larval survival rate was obtained (S. Pitipornchai & B. Nuang-saeng, pers. comm. 1999). An example of a feeding strategy for the hatchery rearing of *M. rosenbergii* is given in Table 7.5. Further details of feeding strategies are contained in Chapters 5 and 6.

Table 7.5 Variations of food amount allowed per larva per day during larval rearing. (Source: Aquacop, 1983.)

Day	*Artemia* nauplii (No.)	Pellets (µg DW)
3	5	0
4	10	0
5–6	15	0
7	20	0
8	25	0
9	30	0
10–11	35	0
12	40	70
13–14	45	80–90
15–24	50	100–180
25–30	45	200
30+	40	200

DW = dry weight.

7.5 References

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8

Nursery Systems and Management

Dallas E. Alston and Célia M.S. Sampaio

Macrobrachium rosenbergii nursery systems are an intermediate stage between larval rearing (Chapters 5 and 6) and grow-out (Chapter 10), in which postlarvae (usually abbreviated to PL) are cultured at high densities from metamorphosis to juveniles. Technically, PL are 'young' juveniles, but for the purpose of this chapter the term will refer to recently metamorphosed larvae ranging in size from 7 to 10 mm and in weight from 6 to 9 mg. The maximum size of juveniles has not been standardised. While nursery systems are used by some farmers, others stock *M. rosenbergii* PL obtained from hatcheries directly into grow-out ponds (Chapter 10). The age of these PL varies because hatcheries maintain them in holding tanks (New & Singholka 1985) or 'happas' suspended in ponds (Chowdhury *et al.* 1993) until they are sold. The maintenance of PL in holding tanks is described in Chapters 5 and 6.

The use of nursery systems as an intermediary stage between hatcheries and grow-out ponds was initially suggested by Ling (1969b) and later became especially important for locations where climatic and water restrictions do not allow continuous culture (New 1990, 1995). This practice generally results in higher production and/or a potentially higher value of harvested prawns (Sandifer & Smith 1975; Ra'anan & Cohen 1982, 1983). Most of the published work on freshwater prawn nurseries took place during the 1970s in Israel (Ra'anan & Cohen 1982; Ra'anan *et al.* 1984) and in South Carolina (Smith & Sandifer 1979b; Sandifer *et al.* 1982, 1983; Smith *et al.* 1983). The objectives of these studies were to extend the growth phase of *M. rosenbergii* in temperate regions where culture was possible only during 6 to 8 months of the year (Sandifer & Smith 1978; Cohen & Barnes 1982).

Nurseries are also employed in tropical and subtropical regions in order to ensure the optimal use of grow-out ponds for larger prawns and to increase the efficiency of food use (New & Singholka 1985). Because PL are stocked at high densities, nursery ponds also utilise resources such as water, land, and labour more efficiently (Alston 1989), making it possible to obtain three yearly cycles and increase productivity (Zimmermann & Sampaio 1998).

Nursery ponds are beneficial because the culturist has more control over water quality, feeding schedule, diet, and predators (Alston 1989). Monthly size frequency sampling in grow-out ponds has revealed a great deal of variability in the population among ponds (Sarver *et al.* 1982). The nursery phase helps provide greater accuracy when stocking juveniles into grow-out ponds. Recovery from poor survival in a nursery pond is cheaper than waiting until harvest in grow-out ponds (New & Singholka 1985). It is easier to monitor and maintain optimal conditions in a small group of nursery ponds than a whole set of production ponds for an extended period after each stocking (Sarver *et al.* 1982).

Juvenile survival is improved because larger animals are hardier (Willis & Berrigan 1977; Sarver *et al.* 1982; Alston 1989; Valenti 1996) and their larger size may allow them to compete more effectively for food with older prawns (J. Glude, pers. comm. 1998). Juveniles are more resistant than PL to predation (New & Singholka 1985), cannibalism, and fluctuating environmental conditions in grow-out ponds (Ling 1969b; Fujimura & Okamoto 1972). Improved accountability of stock is important in a multi-stage rotational system (Malecha 1981). When high mortality rates occur in grow-out ponds, replacement of animals from a nursery pond is easier. Polyculture with carnivorous fish or larger fish may be feasible when stocking larger *M. rosenbergii* juveniles (Cohen *et al.* 1981). However, nursery systems may increase labour costs and juvenile mortality from handling during transportation of juveniles to grow-out ponds. In marine shrimp culture, intensive nursery systems expose crowded PL to disease outbreaks (Jory 1997). However, the advantages of nursery systems generally outweigh the disadvantages.

Nursery systems may be one-phase, two-phase, or multi-phase operations. One- and two-phase operations may combine outdoor and indoor systems. Thus post-larval nursery culture can be achieved in four different systems: indoor, outdoor, cages, and multi-phase nurseries.

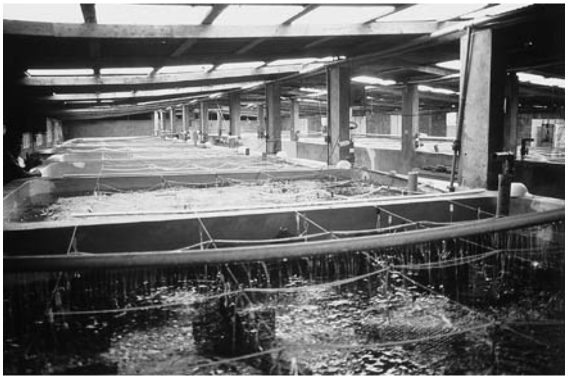

Fig. 8.1 Indoor hatchery, Dominican Republic. Note: parallel support lines (wires) above each concrete square tank are used to hang netting for nursing the postlarvae (PL) indoors for a few days after the larval cycle is completed. (Source: Dallas E. Alston.)

8.1 Indoor (primary) nurseries

Indoor nurseries, also known as first or primary nurseries, vary according to country, climate, region, and management strategy. Indoor nurseries may serve as an extended larval rearing phase (Cohen & Ra'anan 1989) to adapt PL to brackishwater or freshwater. When the post-larval density is above $2/cm^2$ on the tank bottom (or $50\,000/m^3$), newly metamorphosed PL are stocked in indoor nurseries during a 2- to 8-week period (Aquacop 1983). The stocking period is related to density, general hatchery conditions, and the presence of natural foods (Zimmermann & Sampaio 1998). Some culturists use an intermediate holding period (not necessarily nursery stage) to acclimate PL to freshwater or to hold PL for 1 week or so (Malecha 1983). This procedure is used to acclimate PL to temperature and pH. In temperate and sub-tropical regions, indoor nursery culture is carried out at the end of winter. In tropical regions, indoor nursery culture may be performed throughout the year, usually prior to outdoor nursery or grow-out stages (Rodrigues *et al.* 1991).

8.1.1 Facilities

Indoor nursery tanks (Fig. 8.1) are usually constructed from concrete, fibreglass, or asbestos. However, because dislodged particles can endanger the health of workers, the use of asbestos is not recommended. Asbestos is not known to cause any risk to the cultured prawns. The tanks, usually placed inside buildings or greenhouses, may have square, rectangular, round, or octagonal shapes, with areas varying from 10 to $50\,m^2$ (Zimmermann & Sampaio 1998) and depths of about 1 m. Supplemental aeration is provided (Valenti 1996).

Smith & Sandifer (1975) and Segal & Roe (1975) noted that *M. rosenbergii* exhibit aggressiveness and cannibalism when stocked at high densities. Postlarvae and juveniles are susceptible to intra-specific attacks during moult and postmoult stages. Aquatic plants, palm leaves, branches, pebbles, or shells may be placed into nursery tanks to provide shelter for animals to increase survival rates (Ling 1969a; Fujimura & Okamoto 1972; Sandifer & Smith 1977). To avoid inefficient and impractical natural habitats, Smith & Sandifer (1975) utilised artificial substrates in high-density tanks to control and minimise aggressive behaviour, including cannibalism. Artificial substrates enhance survival, production, and feed conversion. Indoor nurseries utilise artificial substrates of various designs and materials to increase surface area.

Artificial substrate designs (Fig. 8.2) are often based on a behavioural characteristic of prawns termed the 'edge effect' (Sandifer *et al.* 1983). When substrates are more or less solid layers, prawns

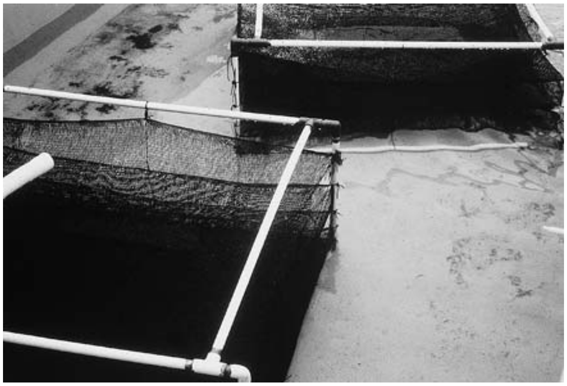

Fig. 8.2 Additional substrate constructed from plastic mesh netting placed in horizontal layers. (Source: Dallas E. Alston.)

exhibit a pronounced preference for the edges. Mesh layers increase the amount of surface edges available to the prawns in both vertical and horizontal planes. Artificial substrates may be constructed with plastic netting (screen) in several layers over wood, aluminium, or PVC pipes (Sandifer *et al.* 1983; Smith *et al.* 1983; Faria & Valenti 1995; Sampaio 1995). Substrates should be suspended from the bottom by about 0.1 m or more to facilitate siphoning wastes. Vertical placement allows larvae easy access to the tank bottom to search for sinking feed rations. In addition, detritus falls to the tank bottom with vertically placed netting, facilitating its removal by siphoning, while horizontally placed netting may complicate cleaning because it collects more detritus. However, Sandifer *et al*. (1983) suggested that 50 mm wide strips placed horizontally could serve as feeding stations incorporated into artificial substrates.

Indoor nurseries may have flow-through or recirculating water systems. In flow-through systems, water continuously enters from tanks, frequently placed above the nursery tanks, and exits at the lowest point of the tank through a vertical standpipe with an outside sleeve (pipe with a larger diameter) extending higher than the water surface. This drainage system draws water from the tank bottom where food waste and detritus settle. Standpipes are covered with a 1 mm mesh screen, preventing PL from escaping (Zimmermann & Sampaio 1998). In spite of the continuous water movement in flow-through systems, tank bottoms need to be siphoned periodically to remove food wastes, faeces, and decomposing organic matter (Borba *et al.* 1993). Some nurseries allow organic matter to accumulate to enable PL to graze on 'lab-lab'.

In recirculating indoor nursery systems water is continuously recirculated through biological filters, which convert ammonia to nitrite, and nitrite to nitrate. Nitrate is less toxic to PL. Irradiation with ultraviolet (UV) lights may be used as a prophylactic water treatment process to control viral and bacterial populations. Because these systems involve limited water change, environmental conditions remain steady. Indoor nursery systems should recirculate water through a biological filter from 3 to 24 times/day (Sandifer *et al.* 1983; Zimmermann & Sampaio 1998).

8.1.2 Water quality

Larval *M. rosenbergii* are more difficult to rear than PL; therefore more attention has been paid to larval water quality. However, PL still require good water quality; mortalities encountered in indoor nurseries using high stocking rates usually result from low dissolved oxygen or high concentrations of nitrogenous compounds (Zimmermann & Sampaio 1998). The oxygen demand of prawns varies as a function of temperature and size (Malecha 1983). Dissolved oxygen levels should be maintained at approximately 5 mg/L in intensive culture (Sandifer *et al.* 1983).

While there is little evidence of special water temperature requirements for prawns kept in indoor nurseries, temperature is a major factor in animal performance. Optimum temperatures for prawns range from 27 to 31°C (Fujimura 1974; Smith & Sandifer 1979a; Sandifer *et al.* 1983). Kneale & Wang (1979) found that best growth rates occurred at temperatures of 28°C, although survival rates were 34% higher at 24°C. Low temperatures decrease growth rate and may cause mass mortality (Coelho *et al.* 1982; Valenti 1985). Growth and survival rates decrease when temperatures are less than 22°C and more than 32°C (Sandifer & Smith 1985). Growth ceases below 19°C and mortality begins at 16°C (Ra'anan & Cohen 1982). Under nursery conditions Sandifer *et al.* (1986) found that temperatures from 20 to 27°C decreased post-larval size variation and increased survival rates, and

Malecha (1983) suggested that PL should not be stocked into water of less than 20°C. Heaters with thermostats may be necessary to maintain constant temperatures. Some indoor nurseries use alternative energy sources such as geothermal water sources or sunlight to minimise their cost (Sandifer & Smith 1985; Redman *et al.* 1990).

A full discussion of water quality in relation to the grow-out of freshwater prawns is presented in Chapter 14, while the importance of larval water quality is covered in Chapters 5 and 6.

8.1.3 Stocking

The transfer of fragile PL from larval rearing tanks to indoor nursery tanks or outdoor nursery ponds is a delicate operation. Recently metamorphosed PL have experienced a drain on their metabolic reserves (Zimmermann & Sampaio 1998). They moult more frequently than adult prawns and their soft shells increase the chance of death by mutilation during handling. The mean weights of PL are usually obtained by taking several sub-samples that are counted and weighed; these are used to calculate the total number and mean weight of the animals stocked into nursery enclosures (and grow-out facilities). Several studies have evaluated automated post-larval counters with errors ranging from about 5 to 7%, with post-larval damage not significantly greater than the sub-sample process described above (West & Thompson 1983; West *et al.* 1983; Welch *et al.* 1989).

Post-larval stocking rates may be related to the maximum load-carrying capacity of the system and the amount of surface area within the tank, and may be expressed both in terms of area (m^2) or volume (m^3). With the addition of artificial substrates, PL will occupy both the bottom of the enclosure and its water column.

A wide range of stocking densities has been employed in experimental nursery systems (Table 8.1), ranging from <200 to >6000 PL/m^2 of bottom area (<200 to nearly 6000 PL/m^3 of water column). High stocking densities in indoor nurseries usually vary from 500 to 6000 PL/m^3, depending on the duration of the culture period (Zimmermann & Sampaio 1998). Sandifer *et al.* (1983) suggested that stocking density should be inversely proportional to the culture period. Higher concentrations result in lower survival rates. Sampaio *et al.* (1996) found survival rates did not change at densities from 200 to 1000 PL/m^3 during 20-day culture periods. Mortality increased with culture periods of 30 days, or with stocking rates above 2000 PL/m^3. Valenti (1996) recommended stocking densities of 2000 PL/m^3 with a substrate surface area of 200 PL/m^2 during a 15-day period. Longer nursery periods cost more, and may exceed US$ 100/1000 juveniles after 60-day periods in indoor nurseries (Faria & Valenti 1995).

8.1.4 Feeding strategy

This section concentrates on feeding strategy and the use of individual ingredients and farm-made feeds in nursery systems. The various feeds used during larval culture in hatcheries are described in Chapter 7; the use of these feeds is sometimes continued in primary nurseries. Feeds manufactured for freshwater prawn grow-out are often used (suitably reduced in particle size) in indoor (primary) and outdoor (secondary) nurseries; nutrition and grow-out feeds are discussed in Chapter 13.

Postlarvae are able to consume larger food items than larvae, such as particles of shrimp or fish, corn, soybean, or wheat (Sampaio 1995). They will also consume larval and adult insects, snails, oligochaetes, fish, and fish faeces, and may cannibalise other PL at high culture densities. Fresh food can be used in small volume tanks using intensive management techniques. Valenti (1996) recommended feeding two separate daily rations consisting of 3 g of beef liver/1000 PL. Borba *et al.* (1993) used one to four separate daily rations consisting of eggs, fishmeal, cod liver oil, powdered milk, molluscs, gelatine, and *Spirulina*; this mixture was cooked in a water bath and sieved.

There is a tendency for nursery operators to supplement diets designed for other species (e.g. catfish, marine shrimp) as diets for prawn nurseries and holding tanks (M. New, pers. comm. 1999). This practice has also been common in research work. For example, Sandifer *et al.* (1983) and Smith *et al.* (1983) suggested supplementing a 25% crude protein ration with a mixture of cooked eggs, fish gonads, squid, fresh fish, and spinach. Molina-Vozzo *et al.* (1995) supplemented a commercial fish feed with 20% beef liver, creating a diet with a protein level of at least 40%, to obtain better growth and survival. Cohen *et al.* (1981) and Ra'anan & Cohen

Table 8.1 Nursed postlarvae (PL) of *Macrobrachium rosenbergii* in various units[a].

	Prawns/m^2		Prawns/m^3 (water column)		Mean weight (g)			Gain/d (mg)	Survival (%)	
Culture unit	Total surface	Bottom		Days	Initial	Final	Net gain			Source
Cylindrical indoor tanks	32	173	172	60	0.022	1.90	1.88	31	73	Mancebo (1978)
Plastic pools	36	n/a	n/a	35	0.040	0.35	0.31	9	74	Mulla & Rouse (1985)
Plastic pools[b]	36	n/a	n/a	35	0.040	0.30	0.26	7	65	Mulla & Rouse (1985)
Plastic pools[c]	36	n/a	n/a	35	0.040	0.23	0.19	6	67	Mulla & Rouse (1985)
Plastic pools	40	n/a	n/a	35	0.040	0.31	0.27	8	83	Mulla & Rouse (1985)
Cylindrical indoor tanks	41	355	197	60	0.042	1.80	1.76	29	94	Mancebo (1978)
Cylindrical indoor tanks	49	416	231	60	0.060	1.60	1.54	26	92	Mancebo (1978)
Outdoor tanks	52	323	346	56	0.050	1.64	1.59	28	92	Smith *et al*. (1983)
Indoor tanks	76	538	350	42	0.700	2.10	1.40	33	84	Smith *et al*. (1983)
Indoor tanks	76	603	571	58	0.100	0.93	0.83	14	91	Smith *et al*. (1983)
Indoor tanks	82	646	612	62	0.260	1.83	1.57	25	69	Smith *et al*. (1983)
Cylindrical indoor tanks	93	797	442	60	0.014	1.20	1.19	20	73	Mancebo (1978)
Outdoor tanks with in-tank gravel filter	107	1078	1568	30	0.310	0.65	0.34	11	86	Sandifer & Smith (1977)
Outdoor tanks with in-tank gravel filter	107	1078	1568	56	0.310	1.15	0.84	15	62	Sandifer & Smith (1977)
Cylindrical indoor tanks	107	577	571	60	0.016	1.17	1.15	19	82	Mancebo (1978)
Cylindrical indoor tanks	115	986	547	60	0.028	0.60	0.57	10	80	Mancebo (1978)
Outdoor tanks	120	1078	1278	30	0.310	0.63	0.32	11	80	Sandifer & Smith (1977)
Outdoor tanks	120	1078	1278	56	0.310	1.13	0.82	15	68	Sandifer & Smith (1977)
Indoor tanks	137	1194	1433	88	0.010	0.32	0.31	4	96	Smith *et al*. (1983)
Indoor tanks	139	515	608	84	0.026	n/a	n/a	n/a	65	Smith & Sandifer (1975)
Indoor tanks	139	515	608	84	0.026	n/a	n/a	n/a	55	Smith & Sandifer (1975)
Indoor tanks	177	1225	1312	67	0.010	0.20	0.19	3	93	Smith *et al*. (1983)
Outdoor tanks[d]	180	1617	1916	30	0.310	0.56	0.25	8	79	Sandifer & Smith (1977)
Outdoor tanks	180	1617	1916	56	0.310	1.06	0.75	13	57	Sandifer & Smith (1977)
Wooden/fibreglass indoor tanks	195	882	3279	77	0.018	0.31	0.29	4	51	Kneale & Wang (1979)
Indoor tanks	210	1658	1571	92	0.010	0.34	0.33	4	83	Smith *et al*. (1983)
Indoor tanks	211	1663	1575	73	0.010	0.44	0.43	6	89	Smith *et al*. (1983)
Wooden/fibreglass indoor tanks	254	882	3279	77	0.018	0.31	0.29	4	42	Kneale & Wang (1979)
Wooden/fibreglass indoor tanks	260	1176	4372	77	0.018	0.37	0.35	5	53	Kneale & Wang (1979)
Wooden/fibreglass indoor tanks[e]	294	1176	4372	77	0.014	0.23	0.22	3	77	Kneale & Wang (1979)
Wooden/fibreglass indoor tanks[f]	294	1176	4372	77	0.014	0.40	0.38	5	47	Kneale & Wang (1979)
Wooden/fibreglass indoor tanks	339	1176	4372	77	0.018	0.24	0.22	3	51	Kneale & Wang (1979)
Indoor tanks	363	2511	2689	77	0.010	0.20	0.19	2	71	Smith *et al*. (1983)
Wooden/fibreglass indoor tanks[e]	368	1471	5902	77	0.014	0.25	0.23	3	64	Kneale & Wang (1979)
Wooden/fibreglass indoor tanks[f]	368	1471	5464	77	0.014	0.43	0.42	5	39	Kneale & Wang (1979)
Indoor tanks	681	5380	5097	89	0.010	0.32	0.31	3	61	Smith *et al*. (1983)
Indoor tanks	794	6276	5946	105	0.010	0.32	0.31	3	32	Smith *et al*. (1983)
Indoor tanks	n/a	515	608	84	0.026	n/a	n/a	n/a	32	Smith & Sandifer (1975)
Greenhouse plastic bottom	n/a	645	600	69	n/a	0.20	n/a	n/a	95	Ra'anan & Cohen (1982)
Open geothermal pond	n/a	1000	1000	100	n/a	0.90	n/a	n/a	50	Ra'anan & Cohen (1982)
Greenhouse plastic bottom	n/a	1000	900	104	n/a	0.20	n/a	n/a	86	Ra'anan & Cohen (1982)
Greenhouse cement bottom	n/a	1000	1000	103	n/a	0.90	n/a	n/a	85	Ra'anan & Cohen (1982)
Indoor tanks	n/a	800–6300	n/a	90	n/a	0.30	n/a	n/a	61	Sandifer *et al*. (1983)

[a] Data are arranged in ascending order by prawns/m^2 (total surface).
[b] With fertiliser, no feed.
[c] With fertiliser and trichlorfon, no feed.
[d] Tanks were covered with *Eichornia crassipes* but only the surface area of plants was used in total surface area calculation.
[e] Temperature maintained at 24°C.
[f] Temperature maintained at 28°C.

(1982) utilised 43% of minced fresh fish (tilapias) twice a day, 46% of live *Daphnia*, and 11% carp ration (25% crude protein) once a day. Although costly, they considered this diet contained essential nutrients. The diet was used with a 100% daily water exchange to minimise water quality and disease problems.

In most nurseries, the amount of food presented varies from 10 to 20% of initial prawn biomass (Sandifer & Smith 1975; Mancebo 1978; Corbin *et al.* 1983; Sandifer *et al.* 1983; Karplus *et al.* 1990; Heinen & Mensi 1991), and diminishes with time. However, Sampaio *et al.* (1997) increased survival rates by increasing feeding rates to 30 to 60% of initial prawn biomass. Increased survival was attributed to increased food availability. In some nurseries, food is supplied *ad libitum* and quantities are adjusted according to the quantity of uneaten food from the previous feeding (Sampaio 1995).

Lovell (1978) suggested that multiple daily rations in prawn hatcheries increase consumption and nutrient intake, reduce losses of soluble nutrients into the rearing water, and minimise food disintegration and wastage. However, Sampaio *et al.* (1997) considered that feeding frequency did not change post-larval development. They fed only one daily ration during the indoor nursery stage. Heinen & Mensi (1991) reported that PL with initial weights ranging from 9 to 16 mg showed higher weight gain and survival rates when fed only a single daily ration. They concluded that the prawns had an opportunity to graze during a 24-hour period on the submersed feed colonised by micro-organisms, thus providing a supplementary food source.

8.1.5 Growth and survival

Prawns ranging from 0.02 to 0.2 g are sometimes described as being in the 'juvenile I' stage. Cohen *et al.* (1981) encountered a heterogeneous individual growth (HIG) effect among juveniles after 50 days of nursery culture, which increases over time in indoor nurseries. These authors noted less growth with less HIG in high-density nurseries (10 000 and 5000 PL/m^3). Male larvae metamorphose into PL before females, shifting population growth curves to the right (Karplus *et al.* 1990). Temperature can also influence size variability (Sandifer *et al.* 1986). Less size variability was encountered at temperatures of 18 to 20°C and 23 to 25°C than at higher temperatures.

Cannibalism appears to be the primary cause of mortality during the indoor nursery stage. *Macrobrachium rosenbergii* individuals exhibit aggressiveness and cannibalism when cultured at high densities, such as in nurseries. Mortalities probably result from poor water quality, cannibalism, and competition for space and food. Survival rates in indoor nurseries are included in Table 8.1. In spite of *M. rosenbergii* being a relatively disease-resistant organism, diseases can cause mortality during the nursery phase. The relative incidence of focal spontaneous muscle necrosis lesions may be an indicator of post-larval fitness (Sarver *et al.* 1982). Diseases affecting *M. rosenbergii* are discussed in detail in Chapter 15.

8.1.6 Harvesting and transport of juveniles

Juveniles are harvested from indoor nurseries in tropical areas whenever grow-out ponds are available. However, in sub-tropical and temperate regions, prawns are usually maintained at optimum temperatures in indoor nurseries until the grow-out ponds reach temperatures of 20°C.

Nets or dip nets (3 mm mesh) are used to transfer juveniles from the indoor to the outdoor nursery or to grow-out ponds (Borba *et al.* 1993). Estimates of the numbers of juveniles present are based on counting and weighing several sub-samples. More counts are necessary for batches where the size distribution is broad. Counts need to be made during the beginning, middle, and end of each tank harvest. Manually harvested individuals are then transferred to outdoor nurseries or grow-out ponds. However, to reduce stress, animals can be transferred by gravity-induced flow in plastic tubes or through small channels connecting tanks. According to Zimmermann & Sampaio (1998) indoor and outdoor nurseries should be constructed near grow-out ponds to reduce mortality from excess handling and transportation. These workers recommended that, after transporting and stocking juveniles, tanks should be dried, disinfected with chlorine or lime and left to dry for at least 48 h to minimise problems with pathogens.

8.2 Outdoor (secondary) nurseries

Outdoor nurseries (Fig. 8.3), also known as nursery II or secondary nurseries, are similar to grow-out ponds. Depending on management strategies, outdoor nurseries can be stocked with newly metamorphosed PL or juvenile I prawns which come from primary nurseries. They are cultured in the outdoor nurseries from 4 to 10 weeks until they reach 0.8 to 1.5 g, when they are called juvenile IIs (Valenti 1996; Zimmermann & Sampaio 1998). Other strategies may bypass the outdoor nursery and juveniles may be stocked from the primary nursery directly into grow-out ponds.

8.2.1 Facilities

The tank or pond areas of outdoor nurseries vary from 300 to 2000 m^2 (Valenti 1990). The construction of ponds is described in Chapter 9. Ponds are frequently covered with plastic netting to avoid predators, especially dragonfly nymphs (Insecta: Odonata) (Grana-Raffucci & Alston 1987; Alston 1989; Valenti 1996; Zimmermann & Sampaio 1998). Other management strategies avoid utilising netting by filling nursery ponds 1 to 2 days before PL are stocked (Alston 1989). If clearwater (lacking algae) is used, problems are avoided from photosynthetically induced high pH values. Water needs to be filtered to remove dragonfly nymphs. Mulla & Rouse (1985) suggested that losses caused by insect predation are not as significant as often suggested.

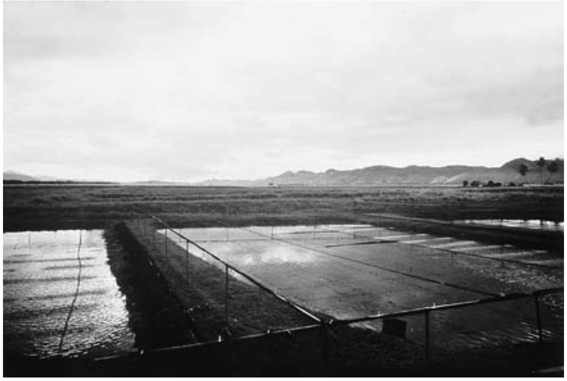

Fig. 8.3 Nursery ponds protected from predators with bird netting. Note: this system was originally used to protect these 500 m^2 ponds from predators. Later, farmers started using unscreened ponds because incoming water was filtered. Predator eggs laid on the surface of the water (e.g. dragonflies) hatch out into forms too small to prey on prawn postlarvae (PL). (Source: Lucy Bunkley-Williams.)

Daily water exchange rates in outdoor nurseries vary from 15 to 30% of the total volume. Supplemental aeration is recommended, but is used rarely because of increased costs (Zimmermann & Sampaio 1998). Artificial substrates such as plastic screens are sometimes used in the outdoor nursery phase. Results are variable, but the substrates may reduce cannibalism, increase survival, increase pond biomass, and decrease mean animal size (Ra'anan *et al.* 1984; Mulla & Rouse 1985).

8.2.2 Water quality

Generally, water quality management in secondary nursery systems is very similar to that employed in the grow-out phase. A full discussion of this topic is presented in Chapter 14.

Sarver *et al.* (1982) studied the low temperature tolerance of 0+ to 4-day-old PL and reported a survival of 76.2% over a 24-hour period at 19°C, but only 3.8% at 17°C. Animals previously reared for 8 weeks at 18 to 20°C and 23 to 25°C displayed rapid growth when temperatures were elevated to 28 to 30°C (Sandifer *et al.* 1986). In 6 weeks, they reached the same size and weight of animals maintained at 28 to 30°C. This growth rate recovery was accompanied by a large variation in size distribution (see Chapter 16). The results suggested size distribution is affected by environmental conditions, and when close to the optimum point, the size distribution curve spreads over a wider range.

Nelson *et al.* (1977) studied metabolic rates of *M. rosenbergii* juveniles for several combinations of water temperature and salinity, concluding that oxygen consumption rate, which is a measurement of metabolic rate, was affected by temperature and animal body weight. At zero salinity, the metabolic rate was higher at 20 to 27°C than at 27 to 34°C. Postlarvae can tolerate a range of salinities and in nature migrate from brackishwater to freshwater after metamorphosis.

Wickins (1976) observed that juveniles could endure (without stress) total ammonia concentrations of approximately 1 mg/L. However, ammonia toxicity increases with pH. According to Straus *et al.* (1991), juveniles should not be exposed to total ammonia concentrations higher than 1 mg/L or 2 mg/L for pH values of 9 and 8.5, respectively. The presence of algal blooms and high pH levels is associated with increased mortality of PL. Postlarvae should not be exposed to pH levels greater than 9.0 for the first few weeks (Aquacop 1983; Hummel & Alston 1984; Hummel 1986; Alston 1989; Straus *et al.* 1991; Díaz-Barbosa 1995). Sarver *et al.* (1982) reported a correlation between high mortality of stocked PL and high pH values over a 4-day period. Hummel (1986), in *in vitro* aquaria trials where pH was adjusted with sodium hydroxide, found that mass mortalities may occur at pH levels at 9.5 or greater. He also tested fluctuations in pH values in greenwater and clearwater on post-larval mortality in outdoor pools. Higher mortalities were recorded for greenwater versus clearwater; maximum pH values rose to 9.9 to 10.5 in greenwater compared to 8.9 to 9.0 in clearwater. Díaz-Barbosa (1995) exposed PL to abrupt chemical adjustments of pH. Mortality over time in these experiments varied with respect to pH. Post-larval mortality was 100% after being subjected to pH 9.3 for 4 h. For pH 9.1, the same mortality was reached after 32 h. Díaz-Barbosa (1995) also determined the effects of gradually acclimatising PL to chemically adjusted pH values in two different systems. In one system pH was decreased from 9.1 to 8.1 and then increased from 8.1 to 9.1. In the other system pH was first increased and then decreased. The results showed that although there was a significant difference between the two systems during the initial stages of the experiments, there was no significant difference in mortality rates at the end of the experiment. He concluded that reduced mortality of PL might be obtained by avoiding pH of 8.9 or greater. According to Straus *et al.* (1991), PL should not be exposed to ammonia-nitrogen (NH_3-N) concentrations greater than 1.0 mg/L when pH values vary from 8.5 to 9. Phytoplankton control may prevent sudden die-offs and subsequent low concentrations of dissolved oxygen. Clarosan (terbutryn) has been suggested as an algicide to reduce photosynthetically induced pH values in ponds (Aquacop 1979). Mortality was low in tanks treated with 2 mg/L for about 10 days.

Hummel (1986) determined the effect of stocking time on post-larval mortality in greenwater and clearwater. Postlarvae were stocked into greenwater and clearwater pools at four different times of day (12:30, 18:30, 00:30 and 06:30 h). Post-larval mortality recorded for the greenwater treatment was significantly higher than for clearwater for all stocking times. Animals stocked in greenwater at 18:30 h and 00:30 h showed lower mortality than animals stocked at other times. At these stocking times (18:30 and 00:30 h), pH values were relatively high (pH 9.8 and 9.6, respectively), but were decreasing. This exposure to high, then decreasing pH, apparently had some acclimation value that lessened mortality in greenwater. Stocking in clearwater with little algae is desirable because high pH resulting from algal photosynthesis can be avoided and post-larval mortality minimised. Thus, the work of Hummel (1986) indicated that, if PL must be stocked with photosynthetically induced high pH, the best stocking time of the day would be during the evening or night when pH is relatively high, but decreasing.

Juarez & Rouse (1983) found that predaceous insects may be controlled with the organophosphate pesticide trichlorfon (dimethyl [2,2,2-trichloro-1hydroxyethyl] phosphate). Juvenile prawns (1 g) had calculated lethal concentrations after 96-hour exposure to trichlorfon of 0.25 mg/L (LC_{15}), 0.46 mg/L (LC_{50}), and 0.62 mg/L (LC_{80}). The results of this study also suggest that PL and juveniles smaller than 1 g may be more sensitive to trichlorfon. Mulla & Rouse (1985) found little growth and survival improvement after treating with 0.25 mg/L trichlorfon in plastic pools and suggested that, while trichlorfon was effective in controlling unwanted insects, unfavourable changes occurred in the natural biota.

8.2.3 Stocking

The stocking of outdoor nursery ponds has previously been discussed in sections 8.1.3 and 8.1.6. Transfer between ponds may be carried out by means of pipes or small channels (Zimmermann & Sampaio 1998). To determine survival rates, a sub-sample of the animals can be evaluated within a mesh bag suspended above the pond bottom. If the survival is poor after 24 to 48 h, more PL may be stocked. Understocking is much easier to remedy than overstocking (Sarver *et al.* 1982).

Outdoor ponds are generally filled several days before stocking; however, the time of stocking varies. Samocha & Lawrence (1992) stocked from 10 to 14 days after filling to increase primary and secondary natural production and to stabilise the pH. However, Valenti (1995, 1996) found that predators and competitors become established quickly, and recommended that ponds should be stocked immediately after filling. Cavalcanti (1997) observed that the density of dragonfly nymphs decreased during the culture period if stocking was done 3 to 7 days after filling the ponds. Ponds laden with *Chara* (Chlorophyta) have more dragonfly nymphs, while ponds with no weeds have more swimming predators such as backswimmers, also known as water boatmen (Insecta: Hemiptera, Notonectidae) (Grana-Raffucci & Alston 1987; Alston 1989). Ponds that are stocked immediately after filling with filtered water have no predators and no photosynthetically induced pH changes. Under these circumstances there may be a slight reduction in growth from the lack of natural food, but increased survival may outweigh this effect.

Stocking densities in outdoor nursery facilities vary between 75 juveniles/m^2 and 1500 PL/m^2 (Alston 1989; Rodrigues & Zimmermann 1997). Aquacop (1983) found that maintaining high densities of PL (10 000 PL/m^3) in hatcheries for more than a few days leads to higher mortality, which usually occurs at the next moult after transfer to earthen ponds. High water exchange rates, diet, and the use of aerators are factors which allow higher stocking densities during this phase.

8.2.4 Feeding strategy

As noted in section 8.1.4, nurseries often use grow-out feeds. The quantity to be fed varies according to water temperature, but is generally about 15 to 20% of prawn biomass (Alston 1989; Valenti 1996). The feeding strategy is also similar to that discussed in section 8.1.4. Culled female tilapia fingerlings from mixed-sex tilapia populations can serve as a protein source after tilapia males have been manually separated for monosex grow-out. The female tilapia may be ground together with equivalent portions of a 32% protein commercial tilapia feed, formed into balls of about 15 cm in diameter, and frozen until they are used in ponds. Since decaying fish flesh may cause water quality problems, this management technique needs to be used cautiously. The use of farm-made feeds is discussed in Chapter 13.

8.2.5 Growth and survival

Sarver *et al.* (1982) suggested that even under the 'best conditions', 10 to 20% stocking mortality should be expected when stocking PL into ponds. They indicated that poor post-larval fitness (as measured by cold temperature tolerance at 17°C and 19°C) may be found only when pond conditions are poor. Heterogeneous individual growth (HIG) of *M. rosenbergii* juveniles is accentuated by morphotypic changes during culture in outdoor nursery ponds. This topic is fully discussed in Chapter 16.

Kneale & Wang (1979) used the term 'breakpoint' to describe increased mortality during handling procedures after the eighth or ninth week following metamorphosis. Animals ranging from 0.13 to 0.4 g were subject to this phenomenon. Willis *et al.* (1976) observed a similar occurrence during the second week, while Sandifer & Smith (1975) observed an increase in mortality between the sixth and eighth week. Kneale & Wang (1979) did not observe these phenomena in tanks or ponds with stocking densities lower than 600/m^2, thus suggesting this phenomenon is directly affected by stocking density. However, these workers did not discuss other effects such as temperature, artificial substrates per tank, average weight, or total pond biomass. More studies need to be done to clarify the breakpoint phenomenon.

8.2.6 Harvesting, grading and transport

Juveniles from 0.2 to 2.0 g are harvested by seining ponds two or three times with a 5 to 6 mm mesh seine, or by emptying ponds completely (Alston 1989; Zimmermann & Sampaio 1998). Juveniles drained from ponds should be trapped in a sufficiently large catch basin or box at the end of the drain or outlet (Alston 1989). The catch structure should not stress the animals. Polypropylene boxes or tanks filled with water from aerated nursery ponds are used to transport juvenile IIs to grow-out ponds. These tanks are furnished with aerators and can be pulled by tractors or trucks. The production costs of rearing juvenile IIs (mean weight 0.07 g; mean length 21 mm) was estimated to be about US$ 34/1000 juveniles (Faria & Valenti 1995) in Brazil.

Ra'anan & Cohen (1983) suggested grading juveniles into two or three groups. This increases productivity by decreasing competition in grow-out ponds by reducing HIG. Daniels & D'Abramo (1994) separated 50-day juveniles into five groups, obtaining a total biomass 43% greater than in non-separated populations. The final value of the harvested prawns was 73% higher. Malecha (1988) suggested that the fraction containing the smallest prawns should be discarded. These matters are further discussed in Chapter 16.

After juveniles are transferred to grow-out ponds, the bottoms of nursery ponds should be disinfected by applying 1 kg of lime/m^2 to kill pathogens.

8.3 Nursing in cages

The nursing of PL in cages is still experimental. Stanley & Moore (1983) studied the growth of 3.3 g prawns stocked in cylindrical cages constructed of 6.4 mm mesh galvanised hardware cloth. The prawns were stocked at low densities of 10/m^2 bottom area during an 8-week period. When fed with a range of bound and unbound versions of three commercial diets designed for broiler chicken, catfish, and marine shrimp, survival ranged from 96 to 100% and the biomass increase from 17.6 to 21.6 g/m^2.

Marques *et al.* (1996, 1998) stocked newly metamorphosed PL into 2 × 1 × 1 m cages constructed from screen with a shade rating of 75%. The animals were fed daily at 100% of their total body biomass. Stocking densities of 2, 4, 6 and 8 PL/L yielded average weights and survival rates ranging from 50 to 28 mg and 100.0 to 79.3%. These authors also stocked cages with 0.19 g juveniles at 50 and 100 prawns/m^2. Feeding rates were 10% of biomass during the first month and 5% during the second month. After 2 months, survival was 86% and 75%, and mean weights were 3.2 and 2.4 g, respectively.

8.4 Multi-phase nursery systems

Two-phase nurseries started to develop in Israel during the early 1980s. Newly metamorphosed PL were stocked for 15 to 30 days during the first phase at densities of 1000 to 10 000/m^3 (Cohen *et al.* 1981; Ra'anan 1983; Ra'anan & Cohen 1984). Juveniles were stocked into the second-phase ponds at lower densities varying from 100 to 200/m^2 for a 60-day period. Survival rates were 92 and 85% for phases I and II, respectively. Commercial grow-out operations incorporating a two-phase nursery system have reported production rates of 4.5 t/ha/yr (Silva & Alencar 1990).

Malecha (1981) described a multi-stage stocking and harvesting system to optimise growth. This theoretical model attempted to incorporate HIG patterns with the potential for compensatory growth. The prawns would be 'thinned out' during the culture period with some animals left in ponds, while others would be transferred to other ponds stocked at lower densities. These scenarios involved two or four ponds. It was envisaged that the first pond would be stocked at twice or three times the optimum stocking density. Subsequent thinning and transfer of the prawns would result in the prawns being reduced to the optimum stocking density or restocked into other ponds at the optimum stocking density. He also suggested size grading to minimise HIG.

Multi-stage stocking systems were used in a commercial freshwater prawn farm in Puerto Rico. The Sabana Grande Prawn Farm originally utilised a culture system based on that of the Weyerhaeuser Company (Alston 1991; J. Glude, pers. comm. 1998). The Weyerhaeuser Company conducted an 8-year research and testing programme in Homestead, Florida, anticipating its application in Brazil. The rationale for their system was to maintain a steady-state mixed population of various sizes or age groups in phase I (juvenile) and phase II (adult) ponds. Postlarvae were acclimated to freshwater over a period of 2 to 5 days, then stocked into a phase I pond at 7 PL/m^2 each month for about 120 days. Design mortality rate in the phase I ponds was 10% per month. After 120 days, 5 to 10 g animals were transferred to phase II ponds. Transferring animals from phase I to phase II ponds proved to be labour intensive, with mortality rates of 15 to 20% per month. The PL which were stocked monthly were not resistant to high pH levels and could not compete for food with older month classes.

Table 8.2 Sabana Grande Prawn Farm modified batch system.

Days	Stocking rate (prawns/m^2)	Phase	Description
2–5	n/a	Acclimation	PL acclimated to freshwater, then transferred to nursery ponds
60–90	200–400	Nursery	PL maintained in nursery ponds until harvest, when juveniles transferred to phase I ponds
60–90 and monthly thereafter	20–30	Phase I (later designated as phase II, or drained)	Juveniles maintained in phase I ponds (juvenile ponds), with transfers of 9–15 g animals to phase II ponds. After the population was reduced, individual phase I ponds either became phase II ponds, to allow adults to grow to marketable size, or were drained and re-filled
Indefinite period, as long as production remained high	4–5	Phase II	Adults maintained until reaching harvest size or ponds were drained and re-filled

PL = postlarvae.

The Sabana Grande Prawn Farm tried the Weyerhaeuser culture system, but then changed it to a modified batch system, which incorporated three phases (Table 8.2). As before, PL were acclimated to freshwater over a period of 2 to 5 days and then stocked into a nursery pond (1000 m^2) at 200 to 400 PL/m^2 for about 60 to 90 days. Survival of PL to juveniles ranged from 60 to 90% in the nursery pond. Juveniles (0.3–0.5 g) harvested from the nursery pond were stocked at 20 to 30/m^2 into phase I ponds (now called juvenile ponds) without existing populations. Juvenile ponds were harvested after 2 to 3 months and monthly thereafter to remove 9 to 15 g animals. These 9 to 15 g prawns were then stocked into phase II ponds (now called adult ponds) with existing populations. The juvenile ponds were then either converted to adult ponds, to allow remaining animals to grow to marketable size, or were drained and refilled. This modified batch system required less space than the original Weyerhaeuser system. Whereas the Weyerhaeuser system used one-third of the total farm pond area for growing prawns through the juvenile stage, the modified batch system required only about one-tenth of this area. In retrospect, improvements in the design could have included drain-harvesting juvenile ponds into a catch basin to reduce seining labour costs and increase survival. Furthermore, nursed juveniles should be graded into at least two size groups and consideration should also be given to holding PL longer in nursery ponds (J. Glude, pers. comm. 1988).

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9

Grow-out Systems – Site Selection and Pond Construction

James F. Muir and Julio V. Lombardi

In this chapter, we describe a range of practical site selection, design and construction issues which affect both the small artisanal pond systems that characterise a large part of the present-day *Macrobrachium* sector, as well as large commercial farms. Whatever the format, the planning, design and development of ponds for grow-out is clearly an important aspect of any *Macrobrachium* project, in terms of the costs of development, the ease and effectiveness of management, productivity, economic performance, longer-term environmental security, and overall sustainability. The aim of the chapter is to provide the necessary background to enable an intending producer to identify and develop a site and system effectively, and thereby to improve opportunities for profitable production. Though stock, feed and labour costs are usually the most critical elements in overall production costs, secure and stable systems, capable of providing the appropriate rearing environments and permitting effective husbandry of the stocks, are fundamentally important in ensuring that these inputs are used to best effect. This chapter should be read in conjunction with the other chapters in this book, which define the optimum operational grow-out parameters, particularly Chapters 10 and 14.

The grow-out of freshwater prawns is generally carried out in earthen ponds. These structures are usually cheap and simple to construct and operate, and with suitable management and simple inputs allow for the development of natural foods such as plankton and benthos, while providing relatively stable water conditions throughout the production cycle. Such features favour the growth and survival of the on-growing stock, and will normally allow producers to minimise the costs of production. Ponds for freshwater prawn culture are broadly similar to those used for fish culture, and can either be built by means of an embankment across a watercourse or by excavating and building up a structure to which water can be conducted by various means. In some special cases, e.g. the 'ghers' of southwest Bangladesh, ponds are formed in rice paddy or other low-lying land, and typically contain an elevated central platform on which rice is grown, either simultaneously or consecutively, and high exterior bunds to protect the pond from flooding.

Embankment or interception ponds are made by constructing a dam across a watercourse, thus using the natural topography of the valley. The objective is normally to create a substantial volume of water with a relatively small and simple embankment, without making the pond too deep and the embankment correspondingly more massive to withstand the water pressure. In some cases, a series of such ponds can be laid out down a valley floor (see e.g. Huet 1986). Though this pond type can be relatively inexpensive for the volume of water held, it has critical disadvantages. As water is drawn directly from the river, pond management and the maintenance of fertility is poor due to the lack of control over incoming water flow. The irregularity of the pond bottom makes seine harvesting very difficult and the dams are susceptible to floods. If ponds are laid out in series, it is almost impossible to manage one pond without affecting the others in the series. For such reasons, this pond type is normally used only for extensive *M. rosenbergii* culture.

The other major pond types, diversion or derivation ponds, are normally built along a watercourse or other water supply, and (subject to the local topography) are laid out to provide a regular structure. The water is provided independently to each pond or group of ponds, and the water source can be fully or partially used. The bottom regularity makes seine harvesting easier. Though these arrangements may be more expensive per pond volume created, the advantages to management and productivity in most cases easily outweigh this. These ponds are therefore widely used for semi-intensive *M. rosenbergii* culture, the most appropriate approach for commercial farms (New & Singholka 1985; Lombardi 1996; Correia & Cavalcanti 1998; Valenti 1998). A further variation on this system occurs when ponds are used as raceways, with a high water exchange, high feeding rates and intensive production. However, though technically viable, these systems tend to have uncompetitively high production costs, and are therefore not widely developed. For this reason this chapter focuses specifically on the design and development of semi-intensive diversion ponds. Further details of the construction of these and other types of ponds and raceways can be found in Bard *et al.* (1974), Wheaton (1977), Huet (1986), and Coche & Muir (1992, 1995).

9.1 Site selection

Semi-intensive ponds are closely dependent on local site features and on the disposition of land, water and other productive elements; therefore good site selection is a fundamental requirement for successful freshwater prawn production. Local features determine the technological level to be employed, the potential production, and the construction and operation costs. The criteria for site selection for *M. rosenbergii* production have been presented by New & Singholka (1985), Valenti (1985), Cavalcanti *et al.* (1986) and Correia & Cavalcanti (1998). Lee & Wickins (1992) described in detail the main features to be analysed when setting up a prawn farm. Perhaps unsurprisingly, there is general agreement regarding the aspects to be considered, such as market access, local social and economic conditions, infrastructure, topography, climatic conditions, water and soils. However, while it may be relatively straightforward to describe the ideal or preferred site conditions, it is unusual for sites to provide optimal requirements in all factors. The practical question then becomes a matter of balancing good and less favourable features to determine whether the overall mix of conditions is suitable.

9.1.1 Strategic issues

It may broadly be assumed that potential developers of a *Macrobrachium* project will have established their overall objectives and will have a concept of their intended output, production plans, approach to management and intended markets. It is outside the scope of this chapter to review the process of identifying and developing the commercial decisions. However, in practice, several situations might commonly be encountered:

- a project concept is broadly in place, and a suitable site has to be located, without pre-definition, to match its objectives;
- it is the aim to develop profitable aquaculture in a certain area or region, *Macrobrachium* culture is a potential activity, and one or more local sites need to be found; or
- a site is available for use, either unused or to be converted from other forms of activity (possibly including other kinds of aquaculture) for the purposes of the project, and requires to be developed as effectively as possible.

The strategic issues of site selection concern all the background, non-biotechnical factors which will have a bearing on the suitability of the site. Lee & Wickins (1992) described these as including markets, roads, labour, and legislation. While all of these may be important, their relative impact will depend on the development situation as outlined above, and on the specific project objectives. Underlying all of these factors will be the basic political, social and economic conditions, i.e. the commercial environment in which the project is to be located. As with other forms of aquaculture, there is a basic requirement for physical and financial safety and security, and for a suitable degree of institutional support. For projects with local social or economic development objectives, local political, institutional and community conditions have to be capable of engaging effectively with aquaculture, and prepared to commit to the project.

According to New & Singholka (1985) a market assessment is a primary requirement. This would establish the farm capacity and technology to be applied. In practical terms, assessment would include location and capacity of markets, and consumer preferences for size and product form. If the objective is to meet international or larger urban markets, product requirements are usually clearly defined, and quality and consistency of supply are key issues. Good quality, cost-effective processing and transport links are therefore critical. For local and smaller urban markets, using local market chains, options for product form and distribution may be more flexible, but local transport and market capacity may be significant. It is important to base market assessments on the intended product (an evaluation based on marine shrimp is unlikely to be valid), and to consider potential competitors supplying the same products, or possible substitutes. Market and commercialisation strategy is discussed further in Chapter 19.

Whether for small farms or large commercial projects, the availability and skill of local people needs to be considered. At the artisanal level, farmers and their families need to have sufficient time available to be involved in constructing and maintaining the ponds and to manage production, and may need to have access to advice and extension support. For commercial projects, a suitably skilled labour resource would be required. The number and skill level of employees is related to farm size and technological level. For larger farms (>5 ha water surface area), staff would typically include a technical manager, plus field technicians and unskilled labour. Regardless of farm size, there would usually be at least one technically skilled person, responsible for planning, co-ordinating inputs and outputs, making strategic decisions, and guiding the workforce, who would be responsible for daily field tasks, such as feeding, collecting water and stock data, and general maintenance. Correia & Cavalcanti (1998) suggested that the ratio of the number of labourers to water surface area (in hectares) is 1:1 and 1:2 for large and small farms, respectively; small farms normally hire short-term help during harvest and other peak work periods. New & Singholka (1985) cited a 40 ha *M. rosenbergii* farm run by only two senior staff and six labourers. Valenti (1985) suggested that though skill levels need to be high for most routine aspects of freshwater prawn farming, it is essential that farms should have specialised technical orientation. The nearby availability of research or training institutions also makes it easier to seek technical advice.

The political and legal framework within the area concerned is important, and relates to both support and control issues. Clearly defined and legally protectable resource rights are essential for any longer-term aquaculture project, whether for small farmers or for corporate producers. The legal establishment of financial systems and company structures makes it possible to finance projects and to manage financial matters reliably. Access to credit for small farmers, and general development support provisions, whether in the form of grants, loans, credit guarantees or partnership or joint-venture support, can also be important. In some cases, taxation incentives may be available whether in setting up a farm or in supporting product development and export promotion. In many countries there is legislation to regulate land use, water abstraction and discharge, as well as the clearing of vegetation and the disruption or destruction of sensitive habitats. Environmental and conservation legislation varies from country to country, and within individual countries. In some cases, environmental impact assessments (EIAs) may be required before development can proceed. Finally, particularly for larger projects, open access to international markets is essential, and support to ensure that products meet international quality and environmental standards is increasingly important. General aquaculture policy and legislative issues are not discussed in this book but an example of the approach to these issues, albeit in a country where *Macrobrachium* culture is unlikely, has recently been provided by New (1999).

A range of physical infrastructure factors needs to be considered. The site should have easy access for its major supplies, its workforce and its markets. Nearby postlarvae (PL) suppliers, food and other necessities are advantageous. Freshwater prawns are perishable, and transport to the consumer should be rapid and reliable, so main and secondary roads should allow good access conditions in all weather conditions. Convenient access to shipping and air services is important for export markets.

A mains power supply is desirable, but not essential for freshwater prawn farms (New & Singholka 1985; Correia & Cavalcanti 1998), as simple production systems can be operated without electrical power, and generators may be used when power is required. The practical options are discussed later. It is advantageous if mains water and waste disposal facilities are available, but it is not essential as alternatives may be found. Contact with key suppliers and markets is also important; telephone, fax and internet access are the simplest and most effective options. Radio or satellite communication networks can be installed when there is no local ground line, or if its quality or capacity is limited.

9.1.2 Topography

The main objectives concerning the physical aspects of site selection are to identify a suitable configuration of land and water resources, in which ponds can be easily and inexpensively constructed and water supplied and carried away in an effective manner. For pond construction, and site development, a key issue is to minimise the quantities of earth to be moved. Flat or slightly sloped lands are generally the most appropriate for pond construction, and slopes close to 2% (2 m in 100 m) usually offer good savings and low earth removal (Wolf 1994). Steeper slopes (>5%) should normally be avoided, as earth moving expenditure may be excessive. In most cases suitable gradients correspond to the middle and lower reaches of river plains, though local geological conditions may determine other possibilities. Sites subject to flooding, land-slips, or erosion should be avoided. However, the Bangladesh 'gher' ponds, and many of the *Macrobrachium* ponds of Thailand, are built by excavating into flat, usually seasonally flooded land, relying on their high bunds to protect against normal flood levels.

Ideally, water should be drawn from above pond level, and discharged below the ponds, allowing water distribution by gravity, thus saving expense. When the water supply is below the pond level, dams may be used to elevate the water level if the topography allows (Valenti 1985), though care has to be taken that these continue to function during low water flow periods. Alternatively, pumps may be used, either to move water into the system, or to drain the ponds. In many cases, a single water source may be available, though sites may also be developed with multiple sources. More simply, 'gher' ponds are generally rain-fed, though water is also transferred in more advanced systems using simple field pumps, as the lack of water exchange limits stock loading and productivity.

9.1.3 Climatic factors

The interaction between site and climate is a primary factor in determining the suitability for pond production of *M. rosenbergii.* Key issues include temperature, rainfall, sunlight and wind exposure, together with dependent factors such as evaporation.

Though modified slightly by pond characteristics and methods of management, temperature is the key determinant of the number of yearly harvests and the most appropriate period for culture. According to Valenti (1996) a site can be used for *M. rosenbergii* culture wherever the monthly average is higher than 20°C for a period of at least 7 months. Temperatures are optimum when the average varies between 25 and 30°C year-round. The importance of temperature for the optimum grow-out of *M. rosenbergii* is discussed fully in Chapters 10 and 14, while grow-out under temperate conditions is discussed in Chapter 11. Sites with large diurnal and seasonal temperature fluctuations should be avoided, in order to reduce stress and maintain optimal production conditions. Inland areas are generally subject to larger temperature variation than coastal sites (Lee & Wickins 1992), but other local factors may also be involved.

The water temperature in the pond system is primarily controlled by the effect of air and ground temperature on incoming water supplies and pond water, by solar warming, and by the cooling effects of wind and evaporation. If water is exchanged rapidly, pond water temperature will be controlled by that of the incoming water; otherwise pond heating and cooling effects will dominate, and will be affected by factors such as pond depth and wind exposure. The temperature of water supplies will depend on their origin. Surface waters exposed to conditions similar to those of the site are likely to have similar temperature ranges, while those affected by factors such as seasonal snowmelt may be notably different. Groundwaters may be more affected by ground temperatures, whose average will be similar to that of the air temperature, but whose range will be less. Generally, the deeper the groundwater source, the closer its water temperature will be to the annual average air temperature. These factors apart, when no data are available regarding water temperature for a site, this can be partially estimated from monthly average air temperatures (Valenti 1996). These values can often be obtained at local meteorological stations for multi-annual periods, from which the corresponding monthly average and ranges can be calculated.

Rainfall, evaporation, air relative humidity, wind speed and direction should also be considered. Ideally, evaporation losses should be equal to or slightly lower than rainfall input, to maintain an approximate water balance. However, in some locations this balance changes seasonally, with cooler high rainfall periods in which water can be stored in deeper ponds, and hotter high evaporation periods in which water supplies diminish. By adjusting production plans, it is still possible to produce one or more crops. Mild winds favour gas transfer between water and the atmosphere, helping to oxygenate the water. However, strong winds can increase water losses by evaporation and may also generate wave action, provoking bund erosion. Malecha (1983) also recommended that constantly cloudy areas should be avoided, as this can make it hard to maintain a steady water temperature because it interferes with solar penetration. Periods of cloud cover of several days' duration may also be problematic in causing algal blooms to crash, thereby upsetting the oxygen balance in ponds. Highly unstable meteorological regions should be avoided. Strong storms and winds increase the risks of flood and erosion damage, and may lead to problems with transport access and power supply.

9.1.4 Water supplies

Prawns (*M. rosenbergii*) are normally reared in ponds supplied with freshwater, although the use of slightly saline water is not precluded (see Chapter 14). Supplies of freshwater can be obtained from surface water, as represented by rivers, lakes, reservoirs, and irrigation channels, or from sub-surface (ground) water. Surface water is the most commonly used in prawn farming. According to Wheaton (1977), groundwaters usually have alkalinity and hardness levels that are acceptable for culturing aquatic organisms, and are free of pollution, predators and competitors. However, they are likely to have low dissolved oxygen (DO_2) levels and high levels of dissolved carbon dioxide, and in some cases may contain toxic gases such as hydrogen sulphide and methane. Though DO_2 levels are generally higher in surface water, they may contain predators and competitor species, suspended particulate material (silt), and pollutants from agriculture, industry or urban sources.

In coastal and estuarine areas, brackishwater may be more easily available for *M. rosenbergii* grow-out, abstracted either from surface or subsurface sources. In many coastal locations, the salinities of local water supplies may vary tidally and seasonally, in association with major rainfall and dry periods. As saline water is denser than freshwater, and unless actively mixed is physically separated at the halocline, it lies below the freshwater level, and extends upward into the lower water column of estuaries, or inward below the freshwater table in sub-surface zones. Here, excessive drawdown from the water table may encourage the ingress of saline coastal waters; during wet seasons, when freshwater levels are higher, this process may be reversed. As with freshwater, brackishwater quality depends on the source of supply; estuary waters are typically highly mixed, with high silt loads, organic matter and biological activity. In developed areas, urban and industrial wastes may be significant sources of contamination. Groundwaters, by contrast, may be relatively clean and free of biological or other risk factors.

Surface water can be abstracted through a suitable system and directed by gravity (Fig. 9.1) or pumped to the pond supply point. If water quality is good and it can be supplied by gravity, this is usually the cheapest and simplest water supply arrangement. Natural (resurgent or artesian) springs can provide excellent water quality, but usually have limited flow rates, and several might be needed to meet the water requirements of a commercial farm. Shallower groundwater can be exploited by means of open cistern-type wells and low head pumps, and can be relatively cheap to develop and operate. In suitably porous strata, flow yields can be good, but in many cases these may be restricted. Deep underground water can be exploited by means of wells, with water quality generally suitable for commercial projects. However,

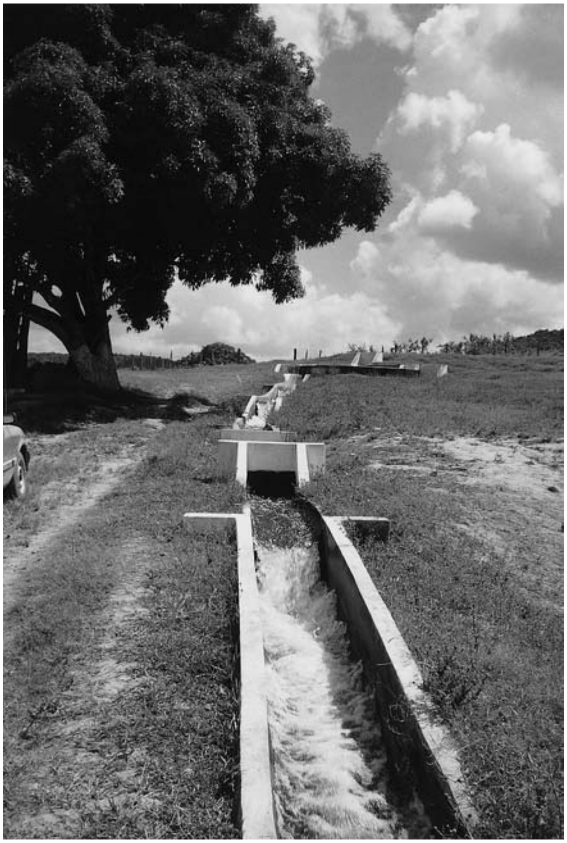

Fig. 9.1 Open channel gravity water supply to a *Macrobrachium* farm in Brazil. (Source: Julio Vicente Lombardi.)

costs may be relatively high. Pumping systems may be economically feasible, but maintenance and operation costs need to be considered carefully in the project feasibility study (Correia & Cavalcanti 1998).

As noted earlier, surface water temperatures are generally closer to air temperatures, while groundwaters tend to have more stable temperatures, equivalent to mean averages. In some cases it may be feasible to mix sources to obtain desired temperatures, or to use different water supplies at different stages or production periods.

Water supply is the key limiting factor in calculating the potential for pond water exchange, and reflects directly on prawn productivity (New & Singholka 1985). For semi-intensive *M. rosenbergii* culture, a continuous flow system is recommended, in order to:

- maintain the pond water level to compensate for evaporation and seepage losses;
- replace organic and inorganic nutrients, essential to support the trophic web of the pond;
- eliminate toxic soluble materials (such as ammonia and nitrite nitrogen) resulting from the metabolic activity of stock and other organisms, and gases (sulphides, methane, etc.) arising from the anaerobic decomposition of organic matter;
- prevent the depletion of DO_2 levels; and
- flush out excessive solids.

Partial water replacement is therefore used to flush ponds to eliminate or reduce algal blooms, avoid DO_2 depletion, or counteract excessive increases in toxic substances or other stress factors. Estimates of water requirements should also include those needed to fill ponds at the beginning of each cycle, together with consumption for use in any supporting facilities such as the laboratory, processing areas, employees' housing, etc. According to Valenti (1985), water requirements for freshwater prawn ponds vary according to local conditions, the principal factors being the incidence and strength of solar input, relative humidity, rainfall, soil permeability, and the degree of pond compaction. Generally, $0.5\,m^3$/min is sufficient to supply 1 ha of surface water area, the equivalent of 13.8 days average residence time for a 1 m pond depth, or a water exchange of 7.2%/day. New & Singholka (1985) suggested flow rates of 0.14 to $0.28\,m^3$/min/ha (2–4%/day) to replace evaporation and seepage losses, and $0.56\,m^3$/min/ha (8%/day) to keep continuous flow in the ponds. Rodrigues *et al.* (1991) and Correia & Cavalcanti (1998) suggested flow rates of 0.12 to $0.18\,m^3$/min/ha and 0.13 to $0.26\,m^3$/min/ha, respectively. According to Lombardi (1996), the ideal flow rate for semi-intensive *M. rosenbergii* grow-out should have the capacity to replace 10% of the pond volume daily. Table 9.1 shows water requirements related to the total area surface water occupied by the ponds.

To estimate water availability at a specific site, a hydrological assessment should be carried out as far as is practicable. For smaller local catchments, an annual and seasonal water balance can be defined, taking into account the area from

Table 9.1 Water requirements for rearing *Macrobrachium rosenbergii* in freshwater ponds. (Source: after New & Singholka, 1985.)

Total farm water surface area[a] (ha)	Maximum pond filling[b] (m^3/minute)	Maintenance flow[c] (m^3/minute) Minimum	Maintenance flow[c] (m^3/minute) Maximum	Average consumption[d] (m^3/minute)
0.2	2.50	0.03	0.11	0.12
0.5	2.50	0.07	0.28	0.31
1.0	2.50	0.14	0.56	0.68
2.0	2.50	0.28	1.12	1.26
3.0	3.75	0.42	1.68	1.89
5.0	6.25	0.70	2.80	3.14
10.0	12.50	1.40	5.60	6.28
20.0	25.00	2.80	11.20	12.57
40.0	50.00	5.60	22.40	25.14

[a] Average water depth 0.9 m.

[b] For filling ponds initially and subsequently and for rapid flushing in emergency. Assumes (1) that the unit pond size is 0.2 ha and that a pond can be filled within 12 h, and (2) that it will never be necessary to fill more than one pond (or 10% of the farm surface area, whichever is the greater) at one time. Local experience will tell if this is either insufficient or excessive.

[c] Continuous water demand, based on 140 L/ha/min minimum and 560 L/ha/min maximum. Actual requirement depends on whether 'continuous' culture is practised or not. The minimum value should cope with average seepage and evaporation losses.

[d] This consists of the maximum maintenance rate, assuming 'continuous' culture for the whole farm, plus the quantity necessary to fill all ponds four times per year, averaged out to a volume per minute consumption basis.

which water can be collected for the site, patterns of rainfall, soils and vegetation over the area and the associated evapotranspiration, and the extent to which water is distributed to surface and sub-surface levels. For larger systems, general data on hydrological conditions may be available, from which estimates of local features may be made. Other uses of water, and the effects of abstraction and discharge will also need to be considered. For lakes and reservoirs, the classical shape and productivity features, seasonal turnovers and other conditions of instability (e.g. wind effects), the size and position of inlets and outlets, and the balance of evaporation from the water surface should be taken into account. For rivers and streams, seasonal patterns affecting flow rate, water levels and water quality should be measured, particularly noting extreme (i.e. flood and drought) conditions. Similar considerations apply to irrigation supplies, though the interaction of the management system with climatic and environmental conditions will also be an important factor. In coastal areas, wind, barometric and tide conditions, and the interaction between fresh and tidal waters through seasonal and tidal variation may all affect the availability and quality of water. For groundwaters, the characteristics of the aquifer (water conducting zone), its depth, permeability and potential yield, need to be determined.

A range of techniques is available for water resource measurement, and can be found in standard sources on hydrology and agricultural water assessment (e.g. ILACO 1981) In many cases, local information may be available and can be adapted for pond culture use. Rodrigues *et al*. (1991) described simple techniques for estimating supply from river or stream flow speed, depth, width, and length data. For more accurate assessment, flow meters or measurement weirs should be used. For groundwaters, local information may be available, test wells dug, or assessments done by specialist contractors.

9.1.5 Water quality

Good water quality is essential for all successful aquaculture enterprises. The relation of water quality to the grow-out of *M. rosenbergii* is discussed in Chapter 14. It will be necessary to ensure that these quality requirements can be met at the site, without complex or expensive treatment or management techniques. The ability to change water easily when required is also very important.

9.1.6 Soils

Good knowledge of physical and chemical properties of available soils is fundamental in determining overall site suitability and the most appropriate methods of pond development. Soils develop from bedrock materials through a range of erosive and depositional geomorphic processes, and may be classified according to constituent particle sizes and their distribution, for which there are established standards (e.g. Coche 1985; Boyd 1995). With the exception of larger particles such as pebbles, cobbles and boulders, which are excluded from analyses, particle sizes range from ≤2 μm (clays) through to 2 μm to 2 mm (fine to coarse silts) to 2 mm to 2 cm (fine to coarse sands) according to the International System (Atterberg Classification). The shape of the particles, as defined by their angularity, and the primary soil origin (e.g. soft calcareous or hard metamorphic rocks) may also be important. Though a range of soil quality parameters can be defined, four primary features need to be considered:

- *Physical strength*: determining the load-bearing capacity of the soil, the ease of carrying out construction work, and the potential for supporting buildings, roadways and other installations. In basic terms, a well-graded soil, with a range of particle sizes, tending to larger, more angular particles, provides greater strength.
- *Permeability*: defining the ease by which water flows through the soil, and hence whether ponds or retention dams will hold water or be subject to seepage. Finer soils are generally less permeable and so a suitable clay and silt content is important. Note that for aquifers, the converse property is required, and larger particles, with higher permeability, are preferable.
- *Plasticity*: determining how well soils will compact to their optimum strength and permeability conditions, and how this relates to the moisture content of the soil (see later). This is related to particle sizes and pore spaces between particles. The stability of the soil under varying moisture conditions is also affected by this property.
- *Physico-chemical interactions*: determined by the surface properties of the soils, the pore sizes and the conditions under which the soil has formed. Finer particles are more reactive, with a higher potential for ionic binding. Larger particles may contain more organic matter and may provide a more open structure for aerobic and anaerobic biological action. The bedrock origin will also determine factors such as pH, and metal content.

If the site has diverse soil conditions, their relative distribution also needs to be considered; this will determine choices of layout, pond location and the most effective means of development. The evaluation of soils will depend on the site type and conditions; in some cases background information may be available (e.g. from agricultural soils analysis or river basin management studies) and should be consulted for primary assessments. Geological and contour maps can also be used to determine whether soils in the area are vertically or horizontally homogeneous, formed through major riverine, glacial or aeolian (wind formed) processes, or are likely to be more diverse. From this information the number, location and depth of the samples required can be considered. In basic terms, flat, lower-lying river floodplains in major depositional areas tend to be more homogeneous, and will normally require fewer samples. Preliminary assessments of particle sizes, permeability and plasticity can be done using simple field techniques, using trial pits or auger samples down to the depths at which it is anticipated soils will be moved (Coche 1985), and from this can be determined the number of samples required for detailed analysis. As an approximate guide, at least three 1 kg samples should be collected for every 1000 m^2 of land with, if necessary, a range of depths (typically every 20 cm down to 20–30 cm below the intended excavation level) and sent to a laboratory for physico-chemical analysis.

The most appropriate soils for pond construction are composed of silt and clay, together with a small percentage of sand, adequate to provide strength and structure to the soil (Coche 1985; Correia & Cavalcanti 1998). According to Malecha (1983), clay silt soils offer better water retention capacity (approximately 85% of water retained over a production period). However, clay content should not be higher than 60% in the total soil composition (New & Singholka 1985), or the soils will be too weak, and will swell and crack under high and low moisture conditions, respectively. The cracking of clay soils in particular can cause problems of leakage, although the soils are themselves relatively impermeable. Sandy soils cause excessive seepage, but water loss can be reduced by constructing an inner key and core in the middle of bunds (Fig. 9.2), filled and compacted with impervious material such as clay (or soil/cement mix). Other techniques to prevent seepage are described in detail by Wheaton (1977).

Rocky soils should be avoided because they make excavation and earth-moving work difficult, and rock outcrops can create major expense in construction. Flooded lands and saturated soils are difficult to work, with reduced excavation yield, or require specialised equipment, and should also be avoided. However, some sites may only be seasonally flooded, and construction can be done outside these periods. In some cases, the soil can be drained and the site protected by a temporary bund to facilitate construction. In coastal areas, soils with a high salt content may be difficult to use, particularly for placing concrete, and care will be required.

There is a lack of specific studies to determine the chemical properties of the most suitable soils for *M. rosenbergii* culture. However, it is known that sulphate and peaty soils are not suitable, as they characteristically have low pH (<4.5), and levels of soluble iron, manganese and aluminium which are harmful to *M. rosenbergii* (New & Singholka 1985; Lee & Wickins 1992; Correia & Cavalcanti 1998). Chapter 14 discusses the management of soils and sediments in the grow-out culture of *M. rosenbergii*.

9.2 Site development

The development of a site for freshwater prawn culture depends on a number of factors, which inter-relate the production objectives and site characteristics. In many cases, the features of the site and the cost and technical feasibility of changing it in certain ways may dictate the options for scale and type of production and the potential layout and dimensions of key features. It may also be necessary to adjust production objectives if the site does not permit the original aims or methods. By this stage, however, it should be possible to establish that strategic issues are satisfactorily resolved, that topographical, soils and landscape features are acceptable, and that access to suitable water sup-

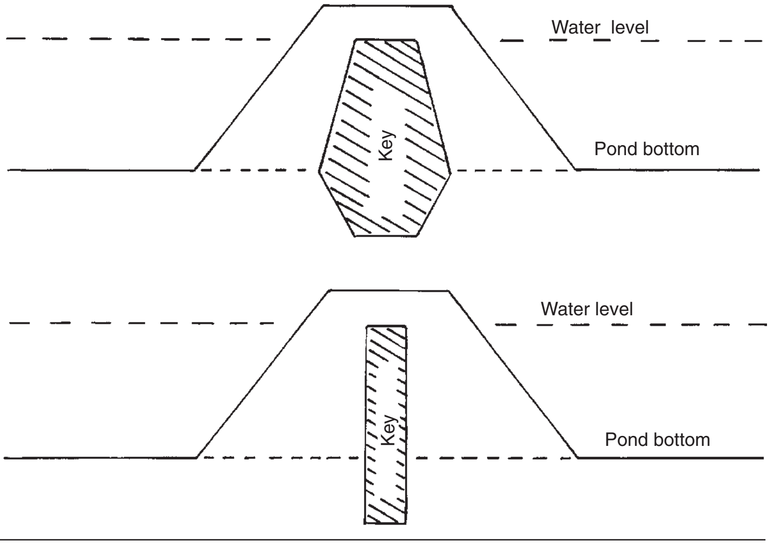

Fig. 9.2 Examples of keys filled with impervious material to avoid seepage

plies and other services is feasible (Coche & Muir 1992). Subject also to the costs of acquiring the site and decisions to finance the project, it may then be possible to plan its construction and development. Key issues at this stage include:

- the overall co-ordination of the scale of the project and its different components, and the confirmation that these will be workable and effective within the site;
- considering future options to expand and develop, and if intended, ensuring that this could be done easily from initial production stages, with minimal disruption;
- decisions about the methods of construction, and how and when this would proceed, considering access to equipment, skills of local staff or external contractors;
- the timing of the different elements of the development, and how this will link with available resources of staff and equipment, materials and components, and with seasonal or other variable factors;
- the administrative issues of developing designs and specifications, obtaining necessary permits, selection of contractors and suppliers, establishing contracts for work to be done;
- proceeding with the development, whether directly or via contractors, ensuring it is carried out to the appropriate standard and in a timely manner, and monitoring and controlling costs; and
- completing the development, cleaning up the site, testing the quality of the completed construction works, commissioning key equipment, obtaining certification if required, commencing production and making final settlements with contractors.

Decisions about these factors, and about whether or not this is to be handled by outside specialists and contractors, depends on the scale and complexity of the project and on the skills and knowledge of the developers. The following sections (9.2.1–9.2.5) outline some of the important practical points.

9.2.1 General considerations

As noted earlier, linkages between the site topography and its water supply are key determining factors in defining the suitability of a site, its potential for development, and the specific locations of individual features. The general objective is normally to develop the site at least cost, and to arrange for simple, low maintenance and trouble-free operation. At a more detailed level, these factors will be particularly influenced by relative site levels, soils and their distribution, and excavation and construction costs. Various regulations may also have to be considered, in terms of zoning permissions, protection of conservation areas, water abstraction and discharge, environmental management, and general construction, building and safety standards. Not all of these may apply, but their potential impact needs to be considered. The timing of development may also be important; in some sites, seasonal variations in rainfall, and the presence of surface water on construction areas and roads, may be critical factors for the ease and cost of construction.

The issue of site development varies greatly with the scale and complexity of the project. At one extreme this may only concern building a simple pond and arranging a convenient inlet and outlet from/to a nearby stream. At the other, it may involve a major production complex, with key elements including ponds, large-scale water and drainage works, buildings of various types and specifications, possibly including offices, sales and other public areas, management and staff accommodation and facilities, ambient or temperature-controlled stores, packing/processing facilities, workshops, garages, pump and generator housings, together with roads, parking areas, power distribution, telecommunications, and potable water supply and sewage treatment facilities.

In all cases, and regardless of the scale of construction, it pays to take a well-organised and methodical approach, in terms of planning the sequences of development, ensuring that work and materials are of the appropriate quality and are used well, and managing the costs, payments for work and regulatory and other permits.

9.2.2 Water supply development

Once the availability and quality of water is determined for the site, its means of access has to be considered in more detail. The aim is to develop systems which are simple, reliable, easy to access (but difficult to tamper with), and inexpensive to develop. For practical reasons of cost, for everything up to very large-scale projects, it is not usually feasible to draw water supplies more than ~1 km from the pond site. The water supply system typically includes an abstraction point, often including various screening or filtering devices, a distribution system of channels or pipes, the various devices for controlling and directing water in the system, and the distribution system for conducting waste or discharge waters away from the ponds. Other components may include pumping installations, storage reservoirs and treatment lagoons, and specialised control and treatment devices. However, as the objective is usually to control costs, these are used only when specifically required.

Surface water development is probably the simplest and most common arrangement for most forms of pond farming, including those for *Macrobrachium.* Sources include rivers, streams, reservoirs, lakes, or various water supply or land drainage canals, and water can be abstracted by gravity or pumping. Seasonal patterns of supply (and water level) and water quality are key determinants of design, defining the relative elevations of structures, the need to protect against flooding or ensure sufficient access in low flow periods, and the need to screen or filter the water prior to use. The intake structure should therefore be capable of abstracting water at the lowest expected water levels in the supply source, protect the downstream system from flooding (and be strong and secure enough to withstand flood conditions), and be able to screen out undesired materials.

It is more common to screen out larger particles (e.g. plant and wood debris, waste materials) at the intake, but to allow finer materials to pass into the distribution system to a point where they can be removed. This avoids the risk of blocking the intake, or the need for very frequent cleaning of fine materials. Large particles are typically removed using coarse vertical or inclined screens, preferably steel, or plastic mesh, though basketwork screens can also be used, as long as they are well maintained. If the risk of blockage is not too great, finer particles can be removed at the intake using fine mesh screens or filter boxes. In some cases, carefully designed sand and gravel filters can be constructed in the bed or the side of the water source. In other cases, it may be more convenient to use a water supply reservoir, to allow particles to settle, creating a settling area at some point on the intake supply, or to use filters or screens at the ponds themselves (Coche & Muir 1992).

For gravity supplies, relative elevations during all periods of operation will determine the dimensions of supply systems – pipes or channels – delivering water to the site. For larger flows, open earth or lined channels are usually the cheapest option, but pipes may be convenient for smaller flows, and can be safely dug in to reduce visual disturbance and risks of damage or contamination. In some cases it may be useful to combine sections of pipe and channel, e.g. if supplies are to be run under roads. The transects of supply routes need to be considered carefully to provide a steady fall, and to ensure that velocities keep conduits clear without eroding them. Where multiple ponds are to be fed, it is important to be sure that water will reach all of the ponds during normal operations, as slight changes in level can create unequal flows. Standard texts on hydraulics or irrigation water supply (e.g. Hansen *et al.* 1979; Yoo & Boyd 1994) may be consulted for typical design procedures. If it is feasible to do so, and water is available, it may be worth making supply lines bigger than initially suggested, as it can be expensive and disruptive to enlarge these later.

Pumped systems for surface waters can use a gravity flow type intake, usually with a small sump or pump chamber set behind the intake structure, from which the pump is supplied. Alternatively, the pump may simply be mounted with its own screened intake directly into the supply water. Surface-mounted or submersible pumps may be used; for the former it is important to ensure that the mounting is secure and accessible, and that the intake is submerged below a sufficient level of water at all times (usually a minimum of twice the intake pipe diameter). Many submersible pumps are capable of running at least partly dry, but they should also normally be covered. Provision must be made to ensure that they can be raised for inspection and maintenance. For ponds set up in low-lying flat land, adjacent to irrigation or drainage canals, pump installations may be particularly simple, and in some cases, light, locally manufactured low-head tubular lift or propeller pumps may be used, lifting water 2 to 3 m at most, from the canal and over the pond or supply channel embankment. Overall, it is important to ensure that pump costs are controlled, and so capacity and operating duty have to be well planned.

Groundwater supplies may be abstracted from a number of different sources and in different conditions, ranging from a simple well (often dug adjacent to a surface water supply, providing a simple 'ground filtering' effect) to a tubewell or borehole system. It is advisable to seek local advice concerning the site and type of intake, and to establish the potential flow and quality, and the pumping depth (and hence capacity) required to develop the supply. The same considerations apply to pump installations as they do for surface waters, though specialised systems may be required for deeper boreholes. Though groundwaters are unlikely to require screening or filtration, they may be deficient in oxygen, and may contain higher than desirable levels of toxic dissolved gases or dissolved metals, particularly iron, which may have to be treated.

Where estuarine or coastal water sources are to be used, water systems have to be planned carefully with respect to the position of saline waters and their diurnal, seasonal, and use-related variation to ensure that water of acceptable (low) salinity is available. For open water intakes, water may be taken from the surface, or in some cases from a sub-surface intake point where preferred salinity and water quality can be derived. Groundwater intakes have to be considered carefully with respect to the effects of saline intrusion, where excessive pumping, by the farm or others, may raise the saline water table, resulting in gradually increased intake salinities. The risks, and advice on siting such wells, should be discussed locally.

Depending on need, storage and treatment systems may be incorporated into the water supply. Though they entail additional cost and complexity, these can serve a number of purposes, including:

- storage of water for intermittent supply conditions (e.g. access to lower salinity water during tidal fluctuations, seasonal rainfall). Reservoir ponds are normally used, or widened and deepened supply channels. Their size depends on the storage required, and on conditions such as evaporation and seepage loss;
- deposition of fine solids, and in some cases, removal of pathogen particulates. Sizing depends on the removal levels required. Usually carried out by the use of reservoir ponds. A minimum of 30 min residence time is usually required for removing medium-fine particles and much longer for smaller sizes;
- aeration and oxygenation, either through atmospheric contact and photosynthesis, or through mechanical stirring or oxygen injection. This may also help to precipitate iron, and may reduce dissolved organic matter loadings;
- chemical dosing, e.g. for pH control, sterilisation, flocculation, etc., in tanks or ponds. This is used only in special circumstances and has to be designed specifically for the purpose concerned; and
- collection, mixing and distribution from different water sources. This may take place in mixing tanks or ponds and may concern surface and groundwater. In some cases water may be partially recycled from the farm outlets to conserve and reuse waters.

In most cases, these functions can be satisfied in a single unit, typically an intake/water supply pond, which may be further partitioned for specific functions.

Water distribution and control systems need to be planned to ensure they are capable of delivering the specific flows required, under all operating conditions, to the component parts of the farm. *Macrobrachium rosenbergii* ponds should be planned with individual water supply systems. The waste water from one pond should not be used to supply another (Fig. 9.3), in order to avoid the accumulation of toxic substances in downstream ponds (New & Singholka 1985; Valenti 1991; Lombardi 1996; Correia & Cavalcanti 1998). Layouts should be simple, direct and easy to manage, with convenient access and the means to adjust water flows as required. Small brick, concrete, wood or plastic-lined channels can be used, or pipes, with simple gate structures, weirs or valves. Simple means of estimating water flows such as 'v' notch weirs may also be incorporated. In some cases,

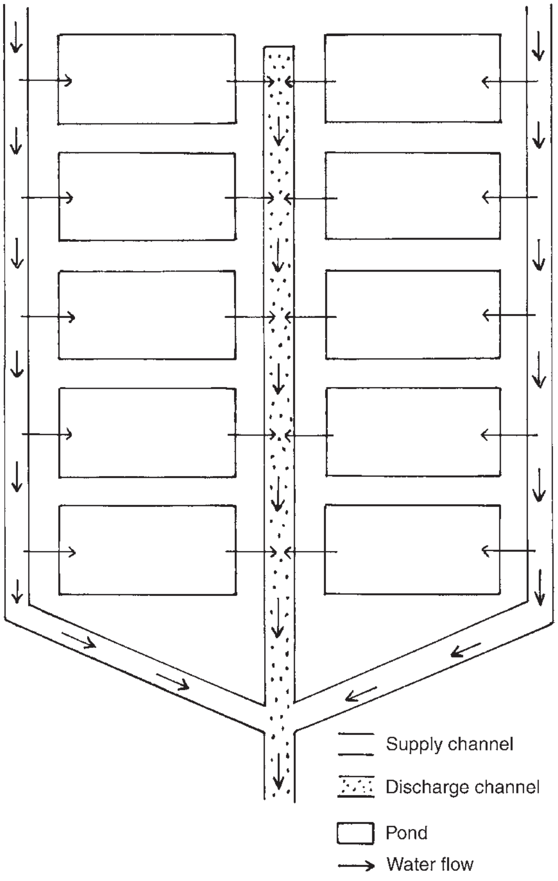

Fig. 9.3 Schematic of parallel derivation for pond water supply

small pumps may be needed for occasional transfers of water.

The final component of the hydraulic system is the waste water collection structure, which has to be designed to be able to accommodate discharge flows from all parts of the farm, including normal operations, drainage and flushing of ponds, and the receipt of intake overflows and local runoff during high rainfall periods. Where discharge is simple and direct to receiving waters, the correct dimensioning of the drainage pipes and canals is the only issue. Otherwise, it may be necessary to reduce solids loads and improve oxygen levels. If additional settling ponds or lagoons are required, it may then be convenient to reuse at least some of the water.

Finally, as water supplies are the most critical features in the successful operation of a *Macrobrachium* farm, it is important to remain aware of the safety factors. Reasonable provisions against drought, floods, silt levels and other water quality changes, power or pump failure, blockages of channels, pipes and flow controls, need to be made.

9.2.3 Pond layouts

The number, size and layout of ponds interlink with site features, water and power supplies, road access and with other construction features. The primary determinant is usually the production planning exercise, which defines the biomass targets, the timing of stocking and harvesting, the crop sizes, and the intended transfer plans (if any) between earlier and later growth periods. In the special case of integrated systems such as 'gher' and other ponds, factors such as agricultural crop planning and the size of crop areas *versus* deeper water areas may need to be considered. Once the primary issues have been defined, the relative size and number of ponds can then be determined, and these can be located appropriately within the site. An important construction objective is to minimise the costs of earth moving, and thus arrangements which balance the volumes of soil 'cut' and 'fill', allowing also for soil balances for other components such as roads and canals, are to be preferred. The need for soils for other purposes, such as flood protection bunds, landscaping, etc., also needs to be considered.

Ideally, the aim should be to provide a logical layout with respect to the flow of water through the site, the movements of stocks from stocking to harvesting, the provision of production inputs, the need for access, and the need for security. For integrated systems, the different components need to be arranged so that they work effectively together. Particularly for larger and more intensive farms, it may be appropriate to define and group subsystems, representing different production stages, management areas, or site zones. Some of the key points are as follows:

- pond size generally increases with the production stage, with small ponds for nursery or early rearing and larger ponds for grow-out. These may

be grouped together, or arranged in separate sections. Final pond size may be linked with harvest batch size;
- large ponds are generally cheaper than small ponds, per volume enclosed, but are more difficult to manage. As ponds increase in size, they require less excavation depth to produce enough material for their bunds. Consequently they are easier to build on lower-lying, flatter ground. The converse applies to smaller ponds;
- where site contours are steep, it is easier to build ponds along the contours rather than across them. However, this may require long supply and drainage systems;
- according to New & Singholka (1985) ponds should be oriented to align with prevailing wind directions to increase natural aeration. Wind action at drainage points can also facilitate water replacement. However, Correia & Cavalcanti (1998) recommended that the ponds should be placed contrary to wind direction to avoid mud accumulation at drainage points. In large ponds, excessive wave action may also increase erosion of pond bunds;
- it is common to arrange for nursery or early rearing stages to be nearer the main centres of activity and infrastructure access, to ensure that they are well protected and managed. They also commonly have the best water supplies;
- in a sloping site, it is usually most convenient to have main access, infrastructure, buildings, and early rearing stages at the top of the site, and grow-out ponds in the lower areas, serviced with a harvest access road; and
- access should be available to all functional parts of the farm, and all ponds should be visible from one or more convenient vantage points. The farm layout may also be screened visually from outside.

9.2.4 Infrastructure

The importance of the availability of external road access, distance to shipping and air ports, and local services has already been noted. At the planning stage it is important to consider the potential infrastructure demands, their timing, and the means by which infrastructure can be made accessible to the site. Local roadworks are usually fairly straightforward, and may be incorporated into site construction activities, though repair and upgrading of public roads may be necessary if the project will generate significant additional traffic. Within the site, it will be important to provide suitable working, turning and parking space for vehicles and equipment.

Power supplies may be more problematic and, if available, will usually require access to the distribution system, the potential need for further transformer capacity, and arrangements for internal distribution within the site. Energy consumption is associated mainly with mechanical aerators, pumps, refrigerators and cold storage facilities, feed manufacture, lighting, office equipment and general-purpose machinery, and will vary with the size and sophistication of the farm. A three-phase power supply is preferable for heavier-duty equipment, but is not essential. In some cases, a direct power drive (e.g. from a diesel or gasoline engine) may be cheaper and more effective. The reliability and stability of the power supply is also important, and protective and control devices may be needed to avoid problems with voltage surges and phase cut-outs. Power may be generated on site, usually with a diesel generator, though solar, wind and hydro-power sources can sometimes be tapped. Where the farm is to have significant dependence on electrical power, a back-up power source, usually a diesel generator, is essential to cover key items.

A range of buildings may be required, as earlier noted. Project offices, work areas, laboratories, housing for managers and employees, processing facilities, stores for feeds, harvesting seines, machines and vehicles, garages, workshops and other units may all be required. Specifications, key dimensions and locations of these need to be considered, together with their service requirements. In some cases it may be convenient and effective to house all functions within a single building; in other circumstances, separate and more specialised units may be advised. Where conventional systems are not available, radio-telephone or satellite communications may be considered. Radio-telephone and other systems are also useful for communicating around the site, for management and safety purposes, particularly for large projects. Protective fences and alarm systems may be needed to limit access to installations, and to improve farm security.

Mains water and waste disposal facilities are an added advantage but are not essential, as provision can be made on site, though this needs to be considered in site selection. Batch supplies of drinking water can be obtained, or borehole or filtered rainwater collected on site. Water for washing and other purposes may be obtained locally. If water is needed for processing and packing, or for ice production, it needs to be of good quality, normally the equivalent of drinking water. Aqueous waste disposal can be carried out either using a septic tank, waste lagoon, or simple soakaway. In some cases a package treatment unit may be considered, though these tend to be expensive for their capacity. Solid wastes may be incinerated, buried in suitably isolated and protected locations, or collected for disposal elsewhere.

9.2.5 Planning pond construction and development

Features of sites and their water supply and pond layout have already been noted, and it is clear that local topography and soils, associated with factors such as access and cost/ease of construction, are important determinants in pond location. Once the overall features of the site have been identified and primary decisions made about relative positions and locations, a more detailed topographic study is necessary in order to plan the distribution of the ponds within the site. This study should provide measurements every 10 to 50 m in unlevelled terrain, at vertical intervals of 20 cm or less. On a very uneven site more detailed measurements may be required. Together with the overall layout ideas, which may be adjusted according to detailed levels, this should determine the best sites and means of development to avoid excessive earth moving during pond excavation. Further information is also provided in section 9.3. Detailed topographical information can also be used to determine the appropriate sequence of development for large sites.

Once these data are established and final decisions about layout have been made, arrangements can be made to set out and mark the main construction features, organise construction plans, obtain planning or other regulatory permits, and finalise agreements for equipment supply, construction contractors, additional workforce, etc.

9.3 Pond system construction

9.3.1 Pond dimensions

The choice of pond size is determined by the technology intended for the project, together with topography, and local climate. In suitable site conditions, larger ponds are generally less expensive to construct per m^2 than smaller ponds, as the bund volume per area enclosed is smaller and as the costs of inlets and outlets do not vary directly with size. However, much less soil needs to be taken from the floor of a large pond to generate sufficient material for its bunds, and so they may be less suitable when site levels require that the ponds are dug deeper into the ground, as too much excavated earth will be produced. Because of the smaller bund area relative to surface area, large ponds also use site space better and, because of their greater water mass and thermal inertia, they are less susceptible to temperature oscillations. However, environmental and other conditions may be more variable across the area of larger ponds, and management may be more difficult. It is common for yields per unit area to be lower in larger ponds under equivalent production conditions.

The individual area of *M. rosenbergii* grow-out ponds generally varies from 0.2 to 0.5 ha (Ling & Costello 1976; Valenti 1991, 1996; Correia & Cavalcanti 1998). 'Gher' and other small-scale integrated ponds may be smaller, from 0.05 ha upwards, but may reach 0.5 ha or more. As noted earlier, larger ponds make management more difficult, particularly with respect to feed distribution, sampling and harvesting. However, some farms have ponds larger than 1.0 ha (Sandifer *et al.* 1983; New & Singholka 1985; Hsieh *et al.* 1989).

Valenti (1985) noted that freshwater prawn ponds can be round, square, or rectangular, though artisanal 'gher' and similar pond types may be quite irregular in shape, depending on individual land holdings. However, rectangular ponds usually offer better and more convenient management conditions. Their length to width ratio typically varies from 2.5:1 to 4:1 (Ling & Costello 1976; Sandifer *et al.* 1983; New & Singholka 1985; Correia & Cavalcanti 1998). Seine harvesting is not very efficient in ponds larger or wider than 30 m (Lam

& Wang 1986). Feed distribution at the centre of the pond also becomes more difficult. Generally, the length of large commercial ponds varies between 100 and 125 m, and the width from 30 to 50 m. It becomes more feasible to use larger ponds when feed can be broadcast mechanically, and seine harvesting can be assisted by tractors or mechanical winches.

The pond base is usually slightly sloped, varying between 0.5 and 1.0% (i.e. 5 to 10 cm per 10 m length) towards the drain, thus allowing the pond to be completely emptied by gravity. The nominal depth of a pond is given by the average between the shallowest (supply end) and deepest (drainage end) point. Thus a pond with 1 m water column at the intake end and 1.5 m at the outlet, has an average depth of 1.25 m. The water depth of freshwater prawn ponds which has been recommended by various authors has differed. New & Singholka (1985) and Valenti (1996) suggested an average water depth of 0.9 m. Rodrigues *et al.* (1991) and Lombardi (1996), respectively, suggested 1.4 m and 1.25 m as a suitable average depth for subtropical regions. Mendes (1992) stated that *M. rosenbergii* can be produced in ponds with a water column varying from 10 to 40 cm in steady temperature regions. Shallow ponds are more utilised in tropical regions. However, this can favour the overheating of pond water and excessive growth of macrophytes on the pond bottom. According to Hsieh *et al.* (1989) and Lee & Wickins (1992), deeper ponds keep more stable temperatures. However, they need to be partially drained to make seine harvesting easier, which may represent an undesirable waste of water in some circumstances.

Pond bunds should normally have a freeboard of 0.30 to 0.60 m above water level to avoid overflow or overtopping through wave action (Wheaton 1977). Therefore, for a pond of 1.25 m average depth with 0.3 m freeboard, the bunds would average 1.55 m in height from the pond base (Fig. 9.4). As noted earlier, for small-scale integrated ponds built in seasonally flooded land, flood levels are another major factor. Here the aim is usually to withstand 10-year floods (according to local experience), and thus the bunds may be elevated 1 m or more above surrounding levels. Internally, depths may be defined by the relative areas of higher rice-growing areas, which are usually at about the orig-

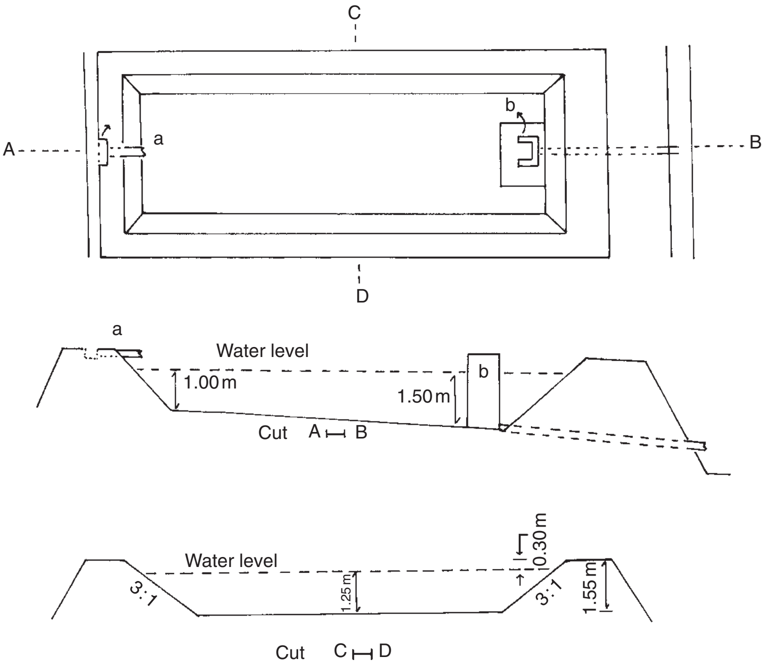

Fig. 9.4 Average depth, bund internal slope and freeboard

Key: a = inlet system; b = outlet system.

inal land level. The excavated areas, typically 0.3 to 1.0 m below this, occupy 15 to 40% of the interior surface.

The slope of bunds is determined according to soil type, relative elevations and practical operational factors. For highly stable soils, the slope of internal embankments is typically at a ratio of 2.5 : 1 (horizontal : vertical). For unstable soils, the minimum slope should be closer to 4 : 1. According to Wolf (1994) the best internal slope for prawn pond bunds is 3 : 1, as this facilitates seine harvesting and avoids erosion (Fig. 9.4). The shallowest regions in the ponds are preferentially occupied by juveniles and recently moulted prawns, while adults occupy deepest areas (Correia & Cavalcanti 1998). Therefore, bunds with a shallower slope at their base may allow better prawn distribution. For exterior bunds the minimum ratio is 1.5 : 1 for stable soils, though they are usually more gently sloped, typically 2.5 to 3.5 : 1. Where the external bund of one pond is the internal bund of another neighbouring pond, the slope should be 3 : 1. In complete contrast to these criteria, small artisanal ponds, such as 'ghers', are commonly built on floodplain areas whose soils typically have a high content of relatively stiff, cohesive and impermeable clay soils. Simple bunds of up to ~0.5 to 0.8 m may be built with slopes as steep as 0.1 : 1, almost vertical, while larger bunds for flood protection are typically set at 0.5 to 1 : 1. All of these bunds require periodic maintenance and rebuilding, particularly as the clay soils crack widely if dried out, e.g. during dry seasonal conditions. However, they are generally acceptable for their purpose.

The crest or top width of pond bunds is usually related to their height (Fig. 9.5), and is also defined by the access required. A further factor may be the need to build water control structures such as sluices, where larger and wider bunds may increase construction costs. Crest widths of 3.5 to 4.0 m, suitable to provide a circulation network for vehicles and machinery, are usually required in large farms. In non-mechanised farms, it is common only for downstream bunds to be wider, thus forming the main access for vehicles. In these cases, lateral bunds are narrower and constitute secondary access, allowing two-wheel vehicles, employees, and traction animals to circulate. The seepage line of the water from the inner pond level to the outer ground surface is also important; if the overall width of the bund is insufficient, seepage losses may be unacceptably high and, more seriously, the bund may be weakened. For this reason the crest may be widened, or the exterior slope decreased. Alternatively, building a core of less permeable material within the bund will restrict seepage and allow narrower bunds.

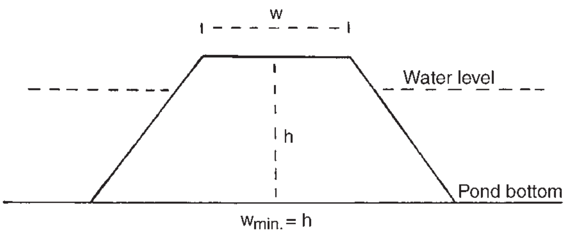

Fig. 9.5 Minimum bund crest
Key: w = width; h = height.

9.3.2 Initial preparations

Even for small projects, a certain amount of planning and organisation is required before any physical construction steps can proceed. Key points include:

- defining layouts, determining whether construction is to proceed in one or more stages, and defining key target dates for completion, particularly if seasonal constraints exist;
- assessing cost, organising finances for the development of the project, and confirming that the project will be viable, based on the timing and potential level of returns;
- adjusting project plans if necessary to meet timing and financial targets;
- producing the necessary documents and obtaining permissions for site development, for water supplies, power, etc.;
- defining how the project is to be developed, e.g. own build, contracted out, or with specific subcontractors for specialised works, and defining the construction period;
- setting up a project management/supervisory function, and assembling or organising a suitable workforce for own construction work; and

- organising bidding and contract documents, assessing and selecting contractors, and ensuring that finance is available and that the site is ready as required for the contractor to proceed.

Before construction starts, initial access ways need to be made, and the land should be cleared and marked out, with external boundaries clearly defined. Site areas for storage of construction materials and for temporary placement of excavated soils should also be identified. For larger-scale projects, a temporary site office/store and a lockable compound may be required for secure storage of tools, equipment and more valuable materials, and for staff and worker facilities. Shipping containers can be conveniently used. Temporary power, freshwater and toilet facilities may also be required. However, if the project is small and simple, and the duration of construction is short, these may not be needed.

A primary site datum point should also be established; this should be a permanent marker, at least during the construction phase, and can either be a prominent and durable natural or man-made feature, or can be fixed once the site is cleared. This provides a reference for distance and elevation for all the subsequent works on the site, and should be positioned so that it is as accessible as possible by line of sight to all parts of the project area. A number of secondary datum points can be referenced to this for triangulation, usually once the site is cleared; where the site has a complex topography, these can also be used to extend the line of sight around major obstacles.

Before clearing the land, the major features of the project (roadways, water supply routes, pond areas, and building foundations) need to be marked in outline, using simple marker poles or coloured cloth strips tied to trees or shrubs, and decisions should be made about which areas need to be stripped of surface vegetation (trees, shrubs, grasses and other plants) and topsoil. Basic cover or topsoil is typically present as an organic layer of about 10 cm depth, with a mixture of soils, pebbles, decayed vegetable matter and plant or shrub roots. In construction areas this layer should be scraped clear, as it cannot be used for normal earthworks. However, the topsoil can be kept for later use to cover the upper surface of pond bunds, roadsides and canal banks and for general post-construction landscaping. Small areas of land can be cleared by hand using agricultural implements, stump pullers and light tractors. For larger areas, scraper tractors can be employed, with a typical capacity of 1000 to 2000 m^2 per 3- to 5-hour work cycle (Wolf 1994).

After scraping, the land should be marked out by wooden stakes to delimit the excavation and construction area. A series of level marks (wooden 'T' or 'H' frames) can also be set out to define key levels and act as local references for excavation, construction or finishing levels. For both horizontal and vertical markers, twine can be stretched between consecutive points to define position and level lines. For ponds, usually the main construction feature, Bard *et al.* (1974) recommended placing stakes within the area marked to build the ponds to form a series of equidistant (usually rectangular) shapes. A line should level the top of the stakes to define the bund crest and depth measurements (Fig. 9.6). Excavation cuts can then be made alongside the position lines. Coche & Muir (1995) showed how the outer line frame defines the outside of the bund, then consecutively the outer bund crest, the inner crest and the inner base of the pond itself. Similarly, position and level lines can be set out for canals, roadways and foundations, and trench positions for pipes, cables, etc., can be identified.

As a broad guideline, major earthworks using larger machinery types are carried out first, followed by smaller and more localised works, involving smaller machinery or manual works. The project is built from the lower levels upwards, and so drainage structures, submerged pipes and power lines, and building foundations are usually placed first, pond bunds, roadways, lower-level building works and surface supply lines constructed next, then above-ground building works, and finally various superstructure elements such as fencing, elevated power and lighting systems, pond equipment, etc. However, this order may be changed, depending on whether there are construction risks (e.g. of heavy machinery damaging newly laid power cables, or according to sub-contractor timetables), or if some parts of the project are to be completed before others.

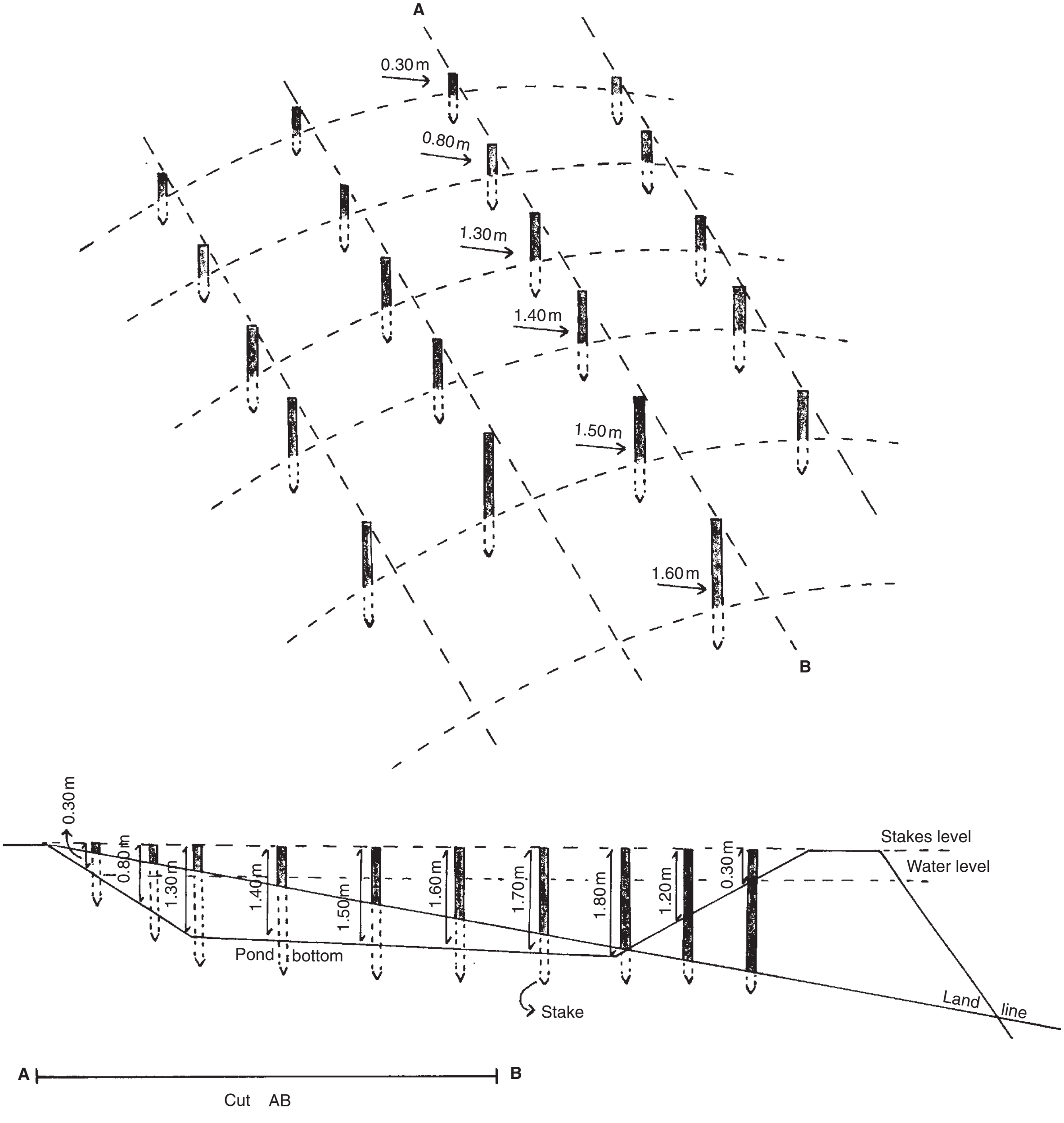

Fig. 9.6 Disposition of stakes for pond construction. (Source: modified from Bard *et al.*, 1974.)

9.3.3 Forming ponds

To reduce earth moving and to ensure that bunds are properly built up, excavation cuts are alternated with earth moving and compaction. According to Wolf (1994), in sloping ground of 2 to 5% gradient, which requires the least amount of earth moving, construction should be made in two stages. The first begins with cuts in the highest area, from which the soil is spread on to the lowest area, forming a flat and well-compacted platform (Fig. 9.7 (a)). In the second step, new cuts are formed, with earth moving to build the bunds (Fig. 9.7 (b)). In slightly sloped land, less than one-third of the total depth of the ponds originates from excavation, generating enough soil to construct the bunds (Fig. 9.8). Coche & Muir (1995) provide a more detailed analysis of these relationships, according to land slope, pond size and depth, and bund width and gradient.

The bunds are constructed by building up successive layers of soil, with thicknesses varying from 15 to 20 cm. Each layer is compacted by a tractor driving over it about four to five times (Wheaton 1977) or, preferably, by using a roller. In drier conditions, the soil should also be moistened to improve its compaction. This procedure can also be used to compact the pond bottom in order to decrease seepage. If pond soils are more permeable, it may be necessary to construct a key trench and an impermeable core. In this case, the trench line needs to be defined, and the trench cut by hand or with a narrow bucket excavator. The core material is then packed into place, and the ordinary soil placed and compacted around it.

Soil removed in excavation undergoes natural increases in volume due to the decompression of soil particles. This phenomenon, which varies with soil type, moisture content and previous compaction history, is known as swell or blistering. A correction factor should therefore be applied in calculating the volumes of earth to be moved. Wolf (1994) suggested a coefficient of 1.43, while Correia & Cavalcanti (1998) considered 1.3 to be

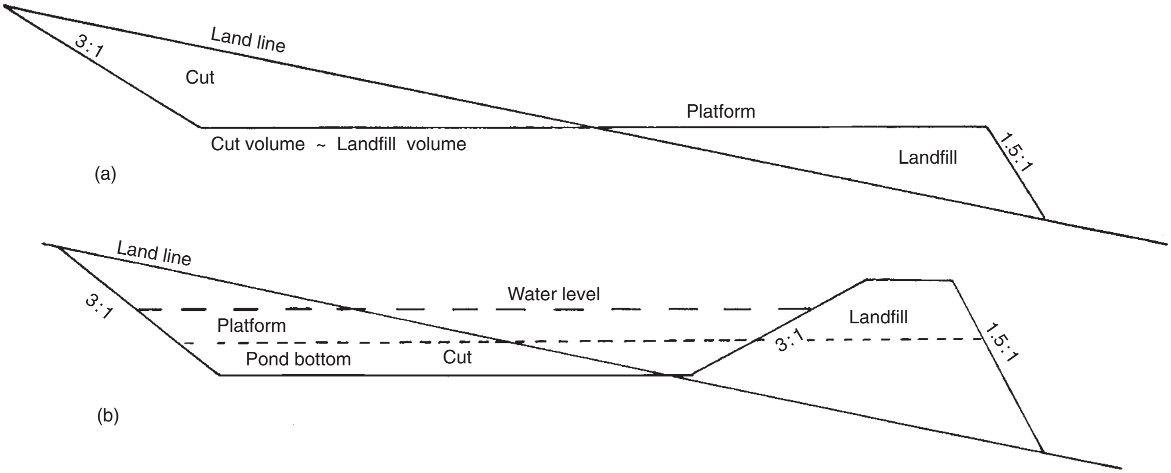

Fig. 9.7 Pond construction scheme for slopes varying between 2 and 5%. (Source: modified from Wolf, 1994.) (a) = Platform construction; (b) = pond construction.

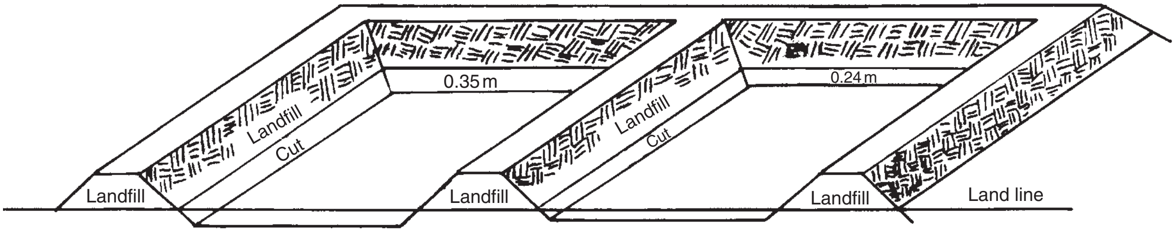

Fig. 9.8 Pond construction scheme for flat or slightly sloping land. (Source: modified from Wolf, 1994.)

appropriate. However, though it is difficult to achieve the original volume after compaction, the final volume may be 80 to 90% of the expanded, loose volume, or around 5 to 10% greater than the original.

As noted, several different types of heavy machine may be used for soil excavation and compaction in larger pond developments. Tractors such as excavators, scrapers, shovellers, and planers are used in excavation, scraping, and levelling, as well as earth movement and placing (Fig. 9.9). For larger volumes and longer distances, dump trucks may also be useful. In difficult site conditions (e.g. where excavated zones are seasonally waterlogged) a Caterpillar-tracked bucket excavator may be useful, in some cases operated from a suitably stable earth or rock platform, with an operating radius defined by the size of the crane arm. Drainage pumps may also be required to de-water construction areas periodically. Standard sheepsfoot or other types of rollers, and Caterpillar-tracked tractors are the most appropriate for compacting bunds and pond bases (Wolf 1994; Correia & Cavalcanti 1998). Tables 9.2 and 9.3 show calculations for earth moving and machine yields under a range of slope conditions and development areas.

For smaller ponds, and particularly in heavier clay soils, manual construction may also be feasible where labour costs are acceptable. Here, excavated soils can be loosened with hoes or cutting tools and loaded into barrows or cribs, and then placed and compacted by hand. Clay soils can be scooped by hand or cut as blocks, and passed hand to hand, to be placed into bund structures.

9.3.4 Water supply

The features of water supply systems, and options for their development, have been discussed earlier. For gravity supplies, concrete, brick or timber sluice gates can be used to control water intake, flow being regulated by stop-logs placed in grooves inside the sluice gates. Water can be transported to the ponds by means of open channels or pipes (Fig. 9.10). Levels of pipes or channels supplying these need to be carefully checked to ensure that flow conditions are as intended. The position and level of supply weirs and sluice gates needs to be co-ordinated with this to ensure that relative water levels are appropriate during all periods of operation. If possible, the construction of water intake structures should be done during low flow periods; in some cases it may be necessary to divert water, or to place temporary protection (e.g. with sandbags or a simple cofferdam) around the construction area to allow the work to be carried out in at least partially dry conditions. Alternatively, it may be possible to build below

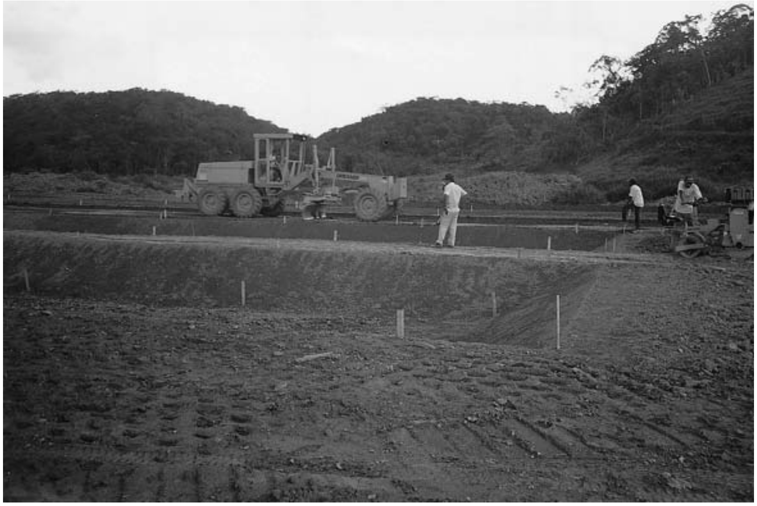

Fig. 9.9 Nursery ponds being constructed in a Brazilian *Macrobrachium* farm. (Source: Julio Vicente Lombardi.)

Table 9.2 Earth moving and machine yield requirements for construction of 3000 m^2 (30 × 100 m) ponds with 3175 m^3 capacity, according to different slopes. (Source: after Wolf, 1994.)

A (%)	B (m)	C (m^2)	D (m^3)	E (m^3)	F (m^3)	G (h)	H (h)
2.5	34.96	3.60	404	1479	2115	46	18 + 18
5.0	37.24	7.66	858	1933	2765	61	24 + 24
7.5	39.87	12.28	1376	2451	3505	77	30 + 30
10.0	42.96	17.58	1970	3045	4355	95	37 + 37
12.5	46.64	23.75	2660	3735	5341	117	46 + 46
15.0	51.07	31.01	3473	4548	6504	142	56 + 56

A = land average slope.
B = required pond width.
C = cut section area required to level the platform.
D = soil volume for platform construction.
E = total soil volume = platform + bund.
F = bund landfill volume, compensated (f = 1.43, where f = expansion factor for loose soil).
G = number of hours of Caterpillar tractor use (86 HP) needed for construction.
H = number of hours of scraper tractor + number of hours of Caterpillar tractor needed for construction.

Table 9.3 Earth moving and machine yields for pond construction under different conditions, area and bund internal slope. (Source: after Wolf, 1994.)

A (m^2)	B	C (m^3)	D (m^3)	E (h)	F (h)
1200	1.5 : 1	539	771	17	7 + 7
1200	3.0 : 1	531	760	17	7 + 7
3000	1.5 : 1	1018	1456	37	13 + 13
3000	3.0 : 1	1075	1538	34	13 + 13

A = water surface area.
B = internal bund slope.
C = bund landfill geometric volume.
D = bund landfill volume, compensated (f = 1.43, where f = expansion factor for loose soil).
E = number of hours of Caterpillar tractor use (86 HP) needed for construction.
F = number of hours of scraper tractor + number of hours of Caterpillar tractor needed for construction.

water and to use pre-assembled structures which can be set into place. It is usually convenient to establish the sluice structures first, and then to link these with the supply channels or pipes.

As noted earlier, channels are usually cheaper than pipes. They may also help to increase water temperatures and DO_2 levels (Valenti 1996), but they require more maintenance. If levels and soils are suitable, they can be excavated directly into the soil using planers or bucket excavators. According to Wolf (1994), a triangular channel section can be made using a scraper, with an output of 450 to 700 m/h. With a bucket excavator, channels are built from 0.3 to 0.5 m width, in rectangular or trapezoidal section, with output ranging from 21 to 46 m/h for dry soils and 12 to 28 m/h for wet soils. To avoid seepage, channels can be covered with plastic or with a soil–cement mixture of ~3 to 6 parts soil to 1 part cement. Alternatively, less permeable soils can be layered over the inside of the channel. Smaller and shorter channels can also be built with lateral bunds of brick or cement block, on a concrete base, typically 0.1 m over a gravel/rock base of 0.2 m. This is a relatively high-cost structure but lasts longer and can carry higher flows for its size. Sivalingham (1974), Wheaton (1977) and Coche & Muir (1992) provided information relating channel dimensions according to water requirements.

Pipes are considerably more expensive, but occupy less space and can be used more conveniently in changing gradients. With sufficient care, and the use of air vents, they may also be used as siphon devices. However, they need to be sized correctly, selected for the appropriate pressure grade, and installed properly. Pipe flow and technical

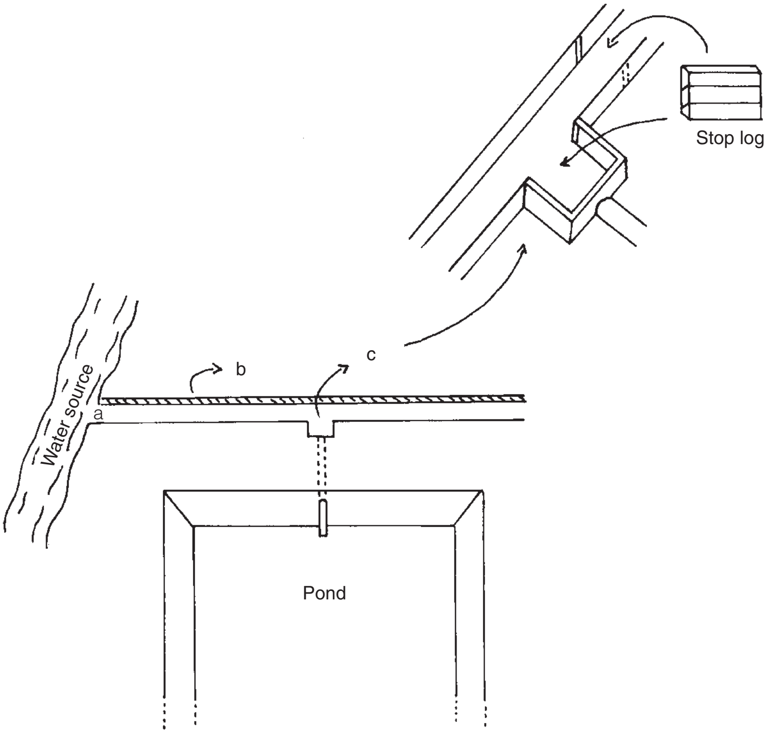

Fig. 9.10 Inlet system

Key: a = collection point; b = transport channel; c = flow distribution.

specifications are normally available from reliable pipe suppliers. It is important to ensure that pipes are properly protected. If installed below ground, they should be laid in a trench, normally cut using a narrow bucket excavator, in which at least 0.1 m of graded sand/gravel bedding material is placed. Joints should be cleanly and securely made, and the pipes filled around with additional material, then graded small rock and, finally, a cover of top soil. Where heavier surface loads are likely (e.g. due to the passage of vehicles), a concrete or concrete slab protection should be provided. Where pipes are surface mounted, they should be securely positioned (e.g. using wooden stakes, clamps or concrete anchor blocks), with at least one fixing for every pipe section (typically 6 m). Special care should be taken to fix the pipe at bends, and at corner or 'T' joints, where pressure surges may shift the pipe or even spring open its joints. Protection should also be provided in busy areas, e.g. using simple fences, guards or bollards or, where vehicle access is required, using a reinforced concrete or concrete slab cover. In such areas it may of course be simpler to bury the pipe. In all cases, access should be provided for cleaning out the pipe. Most pipe suppliers have simple access fittings with screw cap or other closing devices; alternatively, these can be adapted from basic pipe materials, or a simple concrete or brick access box may be constructed.

For both pipes and channel systems, a range of simple connection structures may be required to join flows from different sources, or to split them up to supply different parts of the farm or individual ponds. These are usually brick, concrete block, reinforced concrete or timber boxes, pinned into the substrate or set on a concrete foundation. Typically 0.8 to 2 m wide by 1 to 3 m in length, depending on the flows to be handled and the number and dimension of connecting pipes or channels, these may also have sluices or stop-logs to adjust or close off water flow in particular directions. Coche & Muir (1992) provided typical details.

Inlets are usually constructed once the main pond shape is formed, usually with short channel lengths or PVC pipes, which are more durable and flexible. These are generally installed in shallow trenches dug at a slope of 0.5 to 2%. The inlet system should allow flow adjustments into the ponds. An inlet box is shown in Fig. 9.10, where the water flow is controlled by wooden stop-logs. In pipes, flow adjustments are made by valves or sliding vanes. Alternatively, an inlet sluice may be cut through the pond bund, but these structures are usually much larger, heavier, and more expensive, and are rarely justified. The inlet should be placed in the shallow end of the pond, directly or diametrically opposite the discharge point (New & Singholka 1985). Water should be introduced at least 0.3 m above the pond water surface; it may also be useful to place a deflector or baffle in the pond, to direct the inflow water downwards into the lower water column. Both techniques improve aeration. Mechanical filters in inlets are also useful to avoid introducing predators or competitors into the ponds. Lombardi (1998) gave a detailed scheme of filtration systems used in Brazil.

9.3.5 Outlets

Outlets are normally sited at the lowest construction level, and are built first. Alternatively, the pond bund can be cut through and the outlet constructed. There are two main objectives – to retain water at the desired level, and to exchange water through the pond, drawing from the most suitable level in the water column. Continuous water flow reduces concentrations of toxic substances produced by prawn metabolism and the decomposition of organic matter deposited on the bottom. Prawns are benthic and thus live on the pond bottom, where water quality is not so good. An efficient outlet system should therefore remove water from near the pond bottom, without changing the entire water column. Finally, at the end of the production cycle, the pond needs to be partially or completely drained for harvest and subsequent pond maintenance.

The most effective and widely used outlet system for *Macrobrachium* on-growing ponds is the monk (Figs 9.11 to 9.18). This is usually formed as a tall concrete, brick or wooden box, set in the lower end of the pond, in which one side (usually facing the pond) is open, with sets of grooves to contain one or two sets of stop-logs and at least one outside screen. At the base of the opposite side of the monk, a pipe is set through the pond bund, allowing the water to drain externally. The screen is placed in front of the stop-logs to prevent the stock from escaping during drainage. An extra pair of grooves can also be set into the structure to allow a spare screen to be used when the principal screen is being cleaned. Screens of 2.0 and 5.0 mm mesh are normally used during initial and final stage grow-out ponds, respectively. Flexible plastic screens are usually the most durable.

The dimensions of monks depend on the pond size and depth, typically 1.0 to 2.0 m in height and 0.6 to 1.2 m in width and depth. If more sets of boards and screens are required, the depth usually needs to be greater to accommodate the grooves, which are usually placed ~50 mm apart. For widths of more than 0.8 m, it becomes more difficult to keep stop-logs from twisting and becoming difficult to move. The monk can be placed internally (Figs 9.11 and 9.12) or externally (Fig. 9.13) in the ponds. External monks have all four sides closed, with the boards set inside and a screen placed over the intake pipe on the inside of the pond. This makes access to the boards more difficult than with the open-sided internal monk. Valenti (1996) stated that internal monks can be an obstacle to seining. However, Huet (1986) pointed out disadvantages for external monks, including their vulnerability to theft and acts of vandalism. Another advantage of internal monks is the possibility of removing water from the upper water column, which is sometimes necessary to eliminate algal blooms in flushing operations. Internal monks usually have a larger screen surface, which helps to reduce clogging.

The stop-logs (Fig. 9.14) can be set so that drainage water overflows at the desired pond level (Fig. 9.15). The set next to the screen can be arranged with an opening lower down in the water column to allow lower-level water to be drained from the pond. This is particularly useful for removing excess nutrients. Stop-logs should be made from light, durable and water-resistant materials, typically using timber suitable for boat building. However, some twisting and warping may occur, and leakage between the boards is a common problem. Leakage can be reduced using a simple rubber or plastic flap attached to the lower edge of each board so that this covers the gap between it and the board below. For more long-lasting leakage

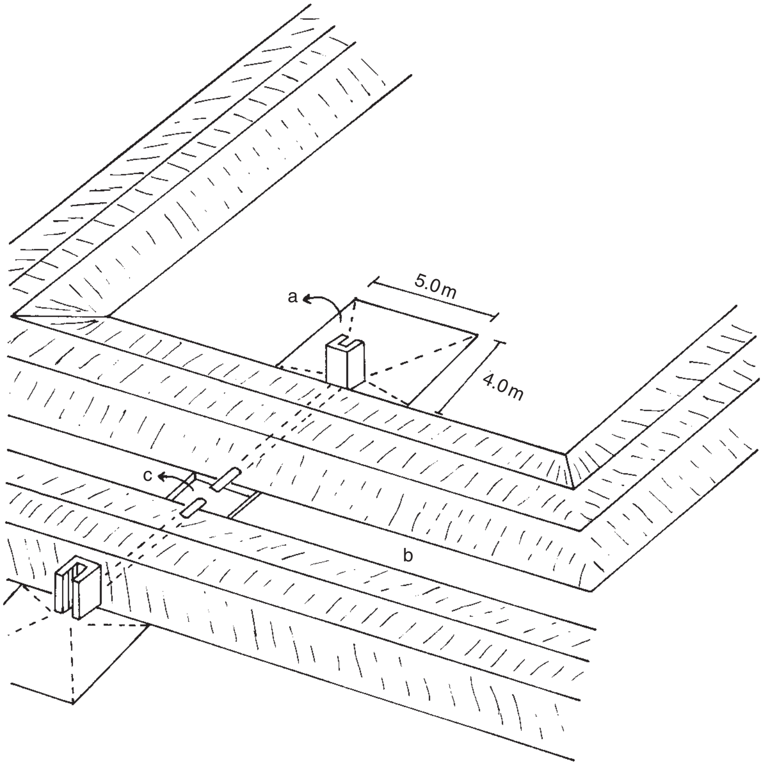

Fig. 9.11 Internal monk outlet system

Key: a = plateau; b = discharge channel; c = discharge box.

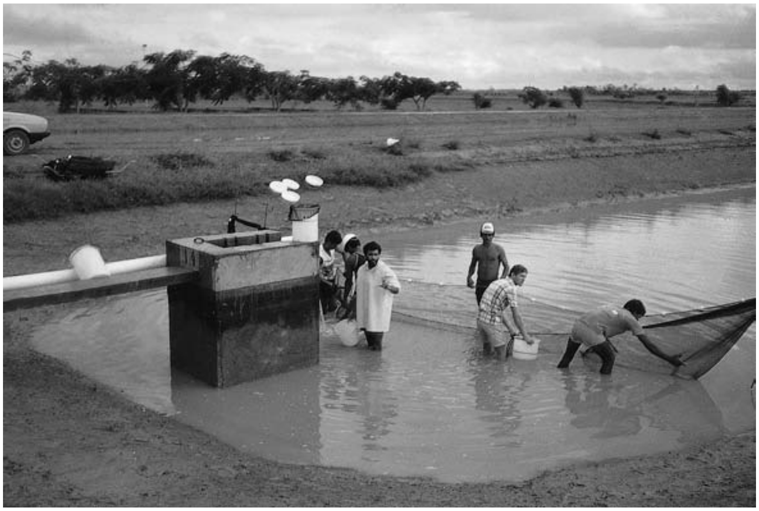

Fig. 9.12 Concrete monk during the drainage of a Brazilian *Macrobrachium* pond. (Source: Julio Vicente Lombardi.)

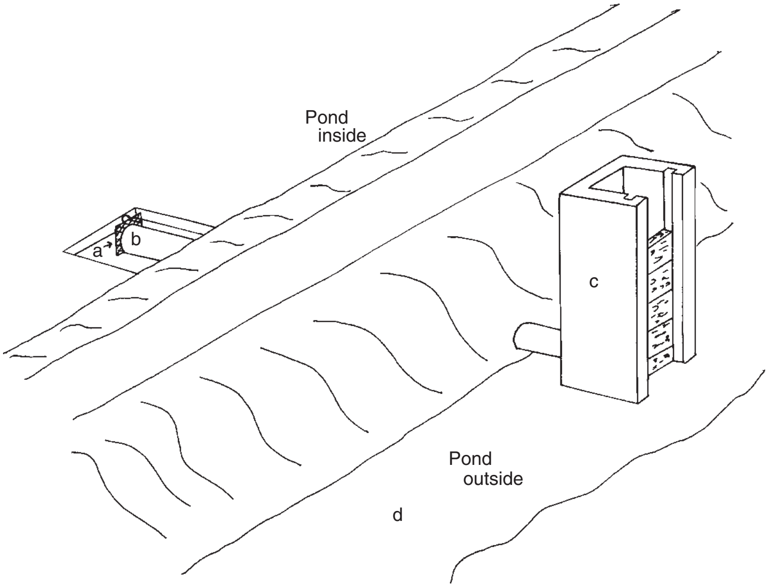

Fig. 9.13 External monk outlet system

Key: a = screen; b = discharge pipe; c = monk; d = discharge channel.

control, mud or clay can be packed between the two sets of boards. Where this is used, a third set of boards on the open side of the monk may be used to control the level from which the pond drains. A brick bund can be an alternative to replace wooden gate boards. In this type of monk, drainage flow control is done by means of removable caps on the end of the drainage pipes (Fig. 9.16).

Ideally, monks should be built in the early stages of the pond construction, set on a secure foundation so that the structure does not move. Critical design and construction aspects include attaching the exit pipe securely to the monk box and securing the pipe well through the pond bund, and preventing seepage around the pipe. Additionally, the base of the pond around the monk and the sides of the bund may need to be strengthened with cobble or a light concrete cover or wooden piling, to protect them from erosion caused by water flow or harvesting activities. The foundations of the monk are typically at least 0.3 to 0.5 m wider than the monk area, usually made of lightly reinforced concrete on a bed of graded rock, or on simple wooden piles. A 20 m^2 concrete foundation platform of 70 mm thickness is set below the ground level as shown in Fig. 9.11 (component a). This is also useful to avoid the deposition of mud around this area, and facilitates harvesting. Discharge pipes are typically 0.15 to 0.3 m diameter concrete, PVC or ABS. Concrete pipes usually need to be jointed at several points through the bund width, while single lengths of plastic pipe may be feasible for smaller bunds. Joints need to be carefully made and the pipe particularly securely fixed at these points, to avoid shifting and subsequent leakage. The foundations are usually extended below the outlet pipe, at least half of the pipe diameter in thickness (Wheaton 1977). Figure 9.17 shows a 0.35 m discharge pipe placed over a 0.18 m thick concrete base.

To control seepage and avoid possible local erosion, metal or concrete anti-seep collars should be firmly placed along the pipes, perpendicular to the line of the pipe (Fig. 9.18). These should be at least 0.05 m wider than the pipe but preferably at least 50% greater than the pipe diameter, and more if the pond soils are loose and easily eroded. As the bund is built up around the pipe, soils should be well compacted around the collars and along the pipes. Once the whole pipe is covered, the rest of the bund may be built up, though care has to be taken in using machinery over the pipe area. Alternatively, the bund may be constructed normally, and then cut through to provide the route for the pipe. After placing the pipe, the soil removed from the bund should be replaced and well compacted.

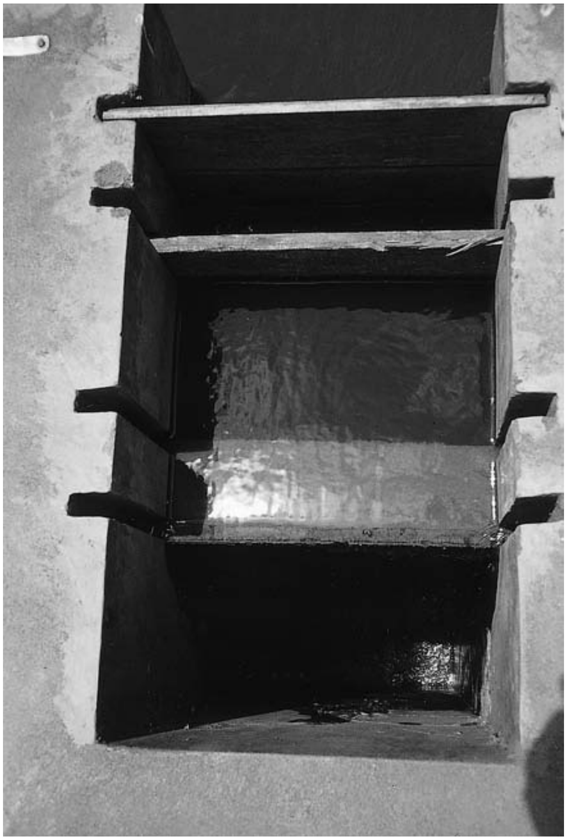

Fig. 9.14 Details of a concrete monk in a Brazilian *Macrobrachium* pond. (Source: Julio Vicente Lombardi.)

The success of this method depends on the type of soil and the care in construction.

Sluice gate structures built through the lower pond bund can also be used for drainage. These are much larger and more expensive than monks for an equivalent size, and so are less commonly used. However, for very large ponds which require a substantial drainage flow, they may be a practical solution, as large monks with very large pipes, or multiple pipes may be just as expensive. Sluices are also far more accessible for cleaning and repair.

For smaller ponds, a pipe outflow may be used to drain water. In its basic form, this is simply a pipe (typically 0.06–0.15 m diameter) run from the interior base of the pond, through the lower pond bund, with a cap or valve at the outer end. As with the monk drain, the pipe should be fitted with one or more collars to restrict seepage. A common variant uses a 90° angle fitting on the outside, holding a vertical pipe extending up to the maximum intended level of the water inside the pond. This 'swinging arm' pipe can then be swivelled down to the required level, or dropped down completely to drain the pond. Both these systems need careful protection against leakage or accidental damage. Additional protection can be provided by connecting a vertical pipe on the inside of the pond. Sometimes, particularly for small ponds, outlet structures may not be used at all; in these cases either a small pump with a simple net screen is set up with its intake at a suitable drainage point, or the outer bund is simply cut through to let the pond drain down.

Where conventional outlets are used, a discharge channel (Fig. 9.11, component b) takes the water to a level below the ponds. Immediately below the discharge pipe a brick, concrete or timber frame and board box can be constructed (Fig. 9.11, component c) to buffer the water impact force and prevent erosion in the discharge channel. In fish ponds, similar boxes may be placed inside the pond to collect fish during total harvesting (Bard *et al.* 1974; Huet 1986). However, placing these boxes outside the pond is better for freshwater prawn harvesting. Such boxes are typically 1.0–2.0 m wide × 1.5–3.0 m long, depending on the size of the pond and the quantity of harvest stock to be held. The discharge channel, usually dug into the site soils, would normally be set at a 0.1 to 0.5% slope (i.e. 0.1–0.5 m per 100 m) along its length. Topographic study (section 9.1.2) should indicate the best route for waste disposal, commonly downstream of the water supply. Channels dug in open soil need constant maintenance to de-silt, remove vegetation, and repair surface erosion. Underground pipes can also be used, if dimensioned according to the maximum system discharge, though provision should be made for access to flush out or scrape clean the pipe interior. Pipes of these dimensions, typically 1 m in diameter or more, can be expensive.

9.3.6 Other features

A number of other technical features may be incorporated into pond systems for *Macrobrachium* production, depending on the management approach, the intensity of production, and local

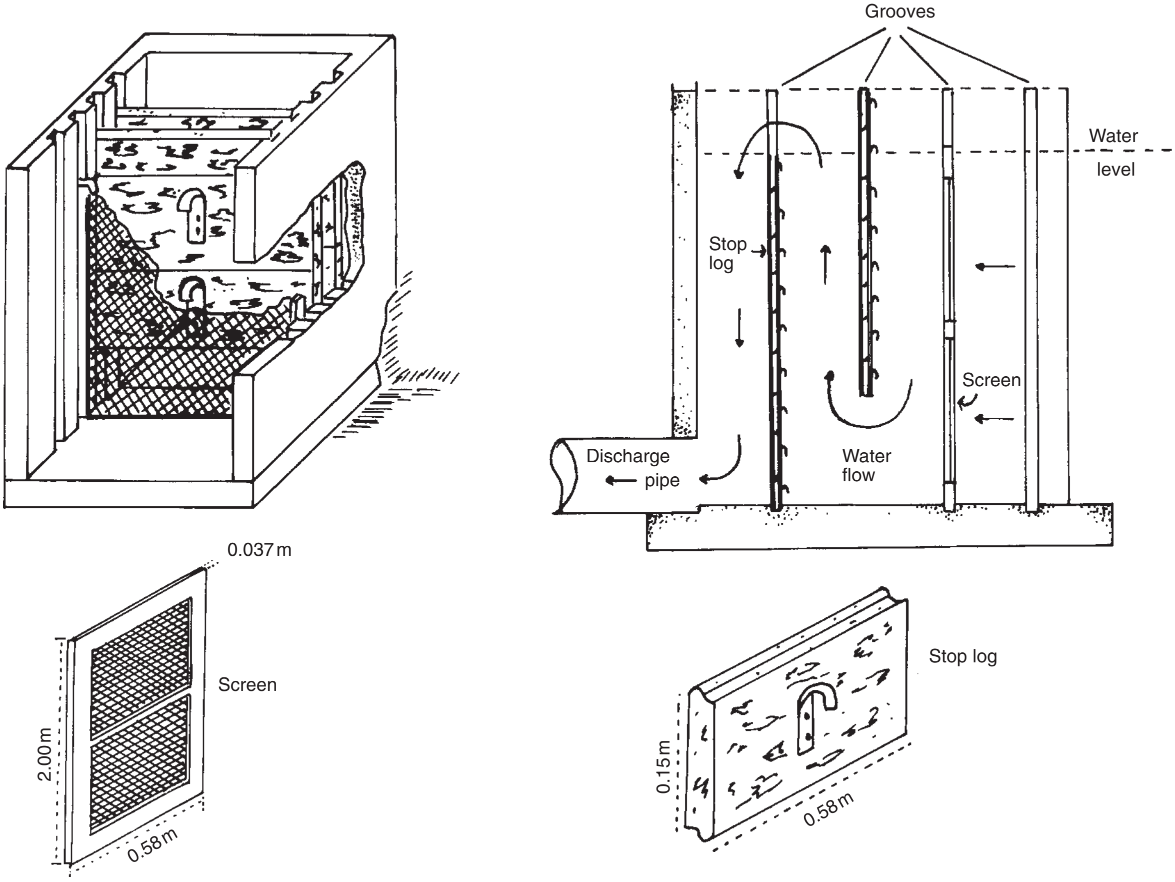

Fig. 9.15 Function of accessories (stop-logs and screen) in a monk

environmental conditions. Some of the more common elements are described as follows:

- *Waste treatment*: in some cases enriched water and waste solids may need to be treated to prevent adverse effects on receiving waters, or to permit some or all of the pond water to be reused at various stages, pumped back for the same ponds, or drained into other systems downstream. Solids removal is the main form of treatment, usually based on sedimentation, in settling ponds. Aeration may be used to increase oxygen levels, and algal growth in the settling ponds may help to remove nutrients.
- *Power supplies*: where aerators are to be used, electrically driven pumps operated, overhead lighting installed, or for various items of field equipment, a power supply network may be required. Cables may be laid below surface, with suitable protection, or run overhead using power lines, ensuring that they are not at risk from damage. Live cables dropping into water can be extremely dangerous, and external lines should be protected if possible with an earth leakage circuit breaker. Sockets should be of suitable external rating, or else placed in secure, waterproof housings.
- *Roadways and access paths*: these need to be constructed in most farm systems, to allow for everyday operations, to move materials and to collect harvested stock. Depending on the soil characteristics, the road or pathways

may need to be reinforced, either with simple piling, with a suitable depth of stones and cobbles, or in some cases, using a light concrete surface, or a brick-lined road bed. Suitable drainage ditches will be needed to allow water to drain from the road surfaces. Simple bridges and culverts may also need to be constructed.

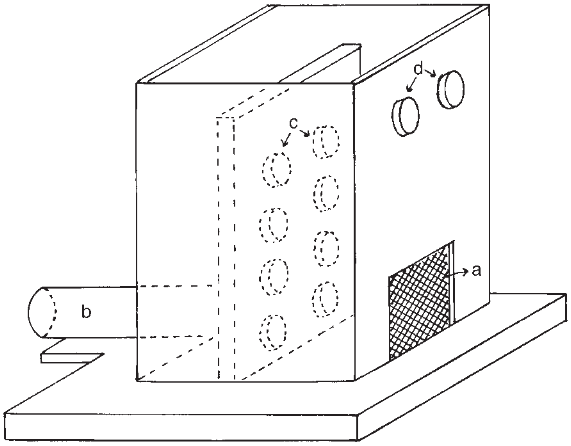

Fig. 9.16 Monk sluice gate in brick bund

Key: a = screen; b = discharge pipe; c = PVC pipes with caps to control flow rate; d = PVC pipes with caps to be used during emergency situations (flushing pond).

- *Feeding devices and storage facilities*: simple tray feeders, made from netting, wood, or plastic, typically 0.5 × 1.0 m and placed every 10 to 20 m, are sufficient for most systems. Suitable provision needs to be made for the storage and efficient delivery of feeds to the pond side.
- *Aerators*: aeration is discussed in Chapter 14.
- *Integrated cropping*: the integration of freshwater prawn culture and crop/livestock production is discussed in Chapter 12.

9.3.7 Landscaping and site finishing

At the end of the pond construction stage, grass should be planted on the bund free-board slopes and crests to avoid erosion. Pieces of turf are preferable to seeding, and can be transplanted from other areas in the farm or from neighbouring areas. The topsoil, which was scraped and set aside before pond construction, can be used as soil cover where grass is to be planted. Other areas of the site may need to be moved and shaped to redistribute surplus soils, to improve site drainage, prevent

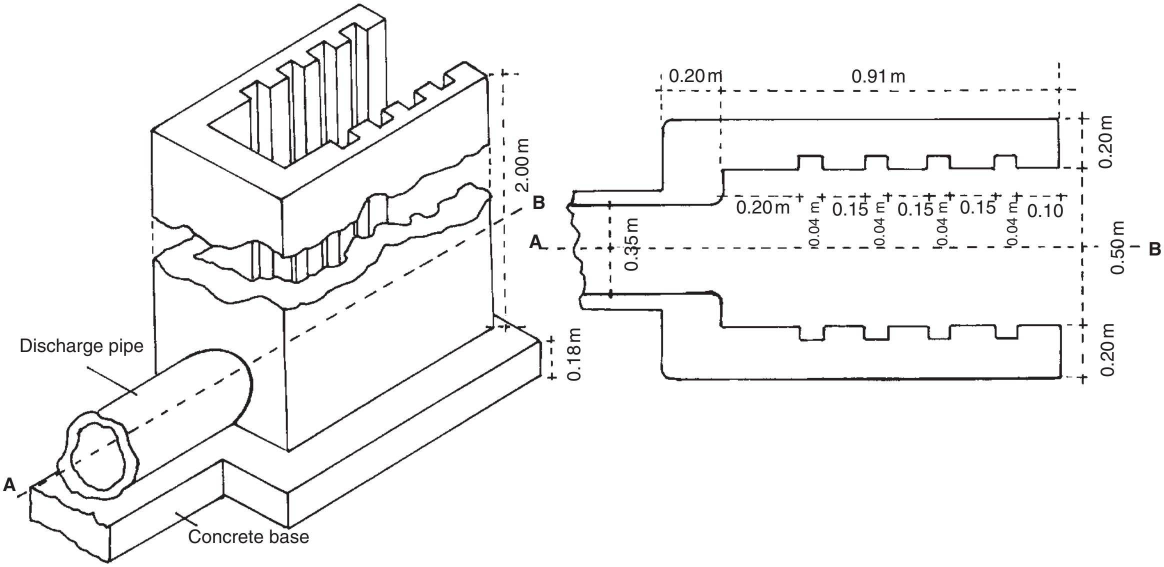

Fig. 9.17 Discharge pipe on concrete base

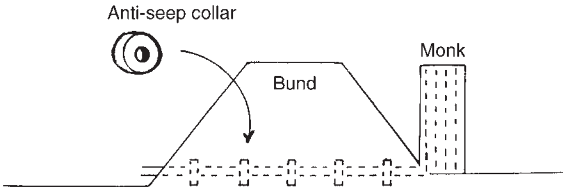

Fig. 9.18 Disposition of anti-seep collars along monk discharge pipe

erosion, ensure effective lines of sight for security purposes, or improve the visual quality of the site. In some cases, the planting of shrubs and trees may be required for visual protection or shelter. Fencing and erection of windbreaks may be required for site security purposes. Finally, the site should be cleared up and made safe and secure.

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10

Grow-out Systems – Monoculture

Wagner C. Valenti and Michael B. New

Freshwater prawns (*Macrobrachium rosenbergii*) have been grown to market size in several types of monoculture systems, in both commercial farms and research centres. They have also been grown in brackishwater, in cages, and in pens but this species is normally monocultured in earthen ponds supplied with freshwater of a wide range of temperatures. This type of grow-out procedure forms the major subject covered in this chapter.

The grow-out of *M. rosenbergii* in ponds has been described in detail in a number of practical manuals and included in various reviews (see Chapter 1). This chapter summarises and updates the information on tropical and sub-tropical management systems found in those publications. Freshwater prawn grow-out management in temperate regions is covered in Chapter 11.

10.1 Rearing systems

Freshwater prawn monoculture may be extensive, semi-intensive or intensive. These systems differ according to the pond design and the level of farmer intervention in the production process. According to the intensity of the system, productivity may range from below 500 kg/ha/yr to in excess of 5000 kg/ha/yr. Lee & Wickins (1992) discussed the productivity of freshwater prawns when cultured at various levels of intensity. However, though the words extensive, semi-intensive and intensive are frequently used in aquaculture, the meaning of these terms has been much confused in the literature concerning *Macrobrachium* culture. Recently, Valenti (1998b) standardised each level of intensity for freshwater prawn culture, as described below.

10.1.1 Levels of intensity

10.1.1.1 Extensive culture

Extensive culture of prawns occurs not only in ponds but also in natural waters and impounded areas built for other purposes, for example in pens constructed in lakes, irrigation canals, and reservoirs, and in rice fields (paddies). Such systems are stocked at low densities (1–4/m^2), using postlarvae (PL) or juveniles which are generally wild-caught. There is no control of water quality, nor the growth or mortality of the prawns, and supplemental feeding is not normally supplied. Prawns feed on natural food but, sometimes, the natural productivity may be increased through the use of organic fertilisers. Prawns are exposed to predators, competitors and other environmental adversities. Usually, it is impossible to drain these bodies of water or to carry out seining; hence the harvesting process is difficult and inefficient. The intervention of the farmers is generally restricted to stocking and harvesting but may include the addition of animal and vegetable by-products as fertilisers or feed. Construction and operating costs are very low and productivity is below 500 kg/ha/yr. This level of intensity has a low environmental impact and requires simple technology and minimal investment. It may be very suitable for promoting social and economic benefits in certain regions, such as Vietnam (Lin & Lee 1992) and the Amazon, where the development of extensive prawn culture might favour the riverine population (Moraes-Riodades 1999; Moraes-Riodades & Valenti 1999).

The extensive system of freshwater prawn culture is commonly practised in Asia, particularly in Vietnam (Lin & Lee 1992). The experimental use of bamboo pens in West Bengal (India) has been reported (N. Kutty, pers. comm. 1999). Recently, it has been reported that 'fence culture' (culture of wild-caught animals within barriers constructed in bamboo) occurs in Vietnam (Hien *et al*. 1998) but the practice is less common than previously, due to a decreasing supply of wild-caught prawn juveniles. The culture of freshwater prawns in pens in China has been noted by Wang & Qianhong (1999). Commercial and experimental production of freshwater prawns in paddy fields has been accomplished in many countries. Integrated culture is discussed in detail in Chapter 12.

10.1.1.2 Semi-intensive culture

Semi-intensive culture is carried out in earthen ponds using a number of management approaches. The location and construction of such ponds is described in Chapter 9. Stocking is accomplished with PL or juveniles of up to 3 months old, in densities which vary from 4 to 20/m^2. Fertilisation and supplemental feeds are applied. Feed, comprised of a balanced ration (Chapter 13), is supplied daily. Predators and competitors are controlled and water quality, prawn health and growth rate are monitored. Construction and operating costs and productivity are quite variable, according to the place and level of technology used. Yields vary from 500 to 5000 kg/ha/yr.

Prawns have been semi-intensively farmed throughout the world under a wide range of environmental conditions and management strategies, which take advantage of the natural potential of the location and the available technology (Valenti 1998b). Most aquaculture technicians consider the management of semi-intensive ponds very simple and they fail to explore its full potential. However, this form of culture exhibits a high degree of biological complexity, as is discussed in section 10.1.2. Semi-intensive freshwater prawn culture has been the most commonly used system throughout the world (Lee & Wickens 1992; Valenti 1996, 1998b). This chapter will therefore focus mainly on this system.

10.1.1.3 Intensive culture

Intensive systems include culture in small earth or concrete ponds (up to 0.2 ha), provided with high water exchange and continuous aeration. Ponds are stocked with juveniles in densities above 20/m^2. Production is totally reliant on the aquafeed presented. Natural feeding is negligible and the animals require an artificial feed which supplies all the nutritional requirements of the prawns. Predators and competitors are eliminated and all water parameters are strictly controlled. Construction and maintenance costs are always high and the productivity can exceed 5 t/ha/yr.

This system is not very compatible with the biological characteristics of *M. rosenbergii*, particularly its social behaviour and heterogeneous growth (see Chapter 16). Until now, it has only been practised on an experimental or pilot scale. Sagi *et al.* (1986) described experimental male monosex intensive culture performed in cages in Israel. These authors estimated that productivity might reach more than 12 t/ha/yr under these conditions. Sebastian *et al.* (1992) described experimental intensive culture in India which was carried out in circular concrete tanks with conical bottoms, but productivity did not exceed 3.5 t/ha/yr. According to New (1995), several pilot studies on high-density culture in controlled closed systems had been performed before 1995, but showed no economic feasibility. However, a pilot commercial project has been in operation in Brazil since 1998 (F. Ugayama, pers. comm. 1999). In this trial, prawns were originally stocked in 16 m^3 concrete tanks, in a recirculation system provided with heaters, and fed a trout ration (44% protein) plus several types of moist food (fish flesh, egg custard, vegetables, etc.). The mean productivity obtained in the first trials was 621 g/m^3/yr (6.21 t/ha/yr). Currently (1999), 58 m^3 indoor tanks are being stocked.

Experimental culture of freshwater prawns in cages has been reported in Thailand (Menasveta & Piyatiratitivokul 1982; New & Singholka 1985) and Brazil (Marques *et al.* 1998; Mendes *et al.* 1998). In each case 2 to 6 m^2 nylon cages were used, suspended in irrigation ditches or grow-out ponds. Results suggested that there was great potential for using this system to produce juveniles and a high biomass of small prawns (about 10 g). Recently, the grow-out of freshwater prawns in cages in China has been noted by Wang & Qianhong (1999). Practised in 15 to 20 m^2 cages situated within lakes, this system is said to yield 1.0 to 1.5 kg/m^2 from a four-stage (increasing mesh sizes) management system (Miao Weimin, pers. comm. 1999).

10.1.2 The ecosystem

A detailed discussion of the general principles of (fish) pond ecology has been provided by Delincé (1992). More recently, Valenti (1995, 1998b) described the specific features of the freshwater prawn pond ecosystem, which are summarised in this section.

Earthen prawn ponds are complex and unique, but resemble other aquatic ecosystems. Dynamic ponds use continuous water exchange and show characteristics intermediate between natural lentic (static water) and lotic (moving water) aquatic environments. Static ponds only replace seepage and evaporation losses, without water exchange; these only demonstrate lentic characteristics.

Grow-out ponds are ecosystems at the first stages of heterotrophic ecological succession. When an earthen pond is filled, a process of ecological succession begins. This process can be heterotrophic or autotrophic, according to the amount of available organic matter at the beginning (Odum 1985). Succession is autotrophic when light is the main source of energy to induce the development of the biotic community. In contrast, the succession is heterotrophic when the event begins in an environment rich in organic matter and organic detritus is the primary source of energy. Freshwater prawn ponds generally receive an application of organic fertiliser before filling with water, which acts as a source of energy for the establishment of initial seral stages (biotic communities). Thus, the succession is typically heterotrophic; detrital food chains and decomposition processes are predominant. Organic fertilisation, feed applied by the farmer, and organic residues carried by the intake water provide the energy to maintain the process throughout the grow-out cycle.

The basic natural factors which affect the pond ecosystem and control its development are the climate (temperature, light, wind and precipitation), the soil in which the pond was constructed, and the chemical and biological characteristics of the intake water. Other factors are introduced and controlled by the pond operator, namely feed, fertilisers, water exchange, and stocking.

The succession in limnic ecosystems is a slow process and, therefore, grow-out ponds are ecosystems in the initial stage of development. Hence, the biotic communities that occur in the ponds are always initial seral stages, constituted by pioneer species. The main characteristics of these communities, which consist of species with a short life cycle (r-strategists or opportunistic species), are high production, elementary biogeochemical cycles, low capacity to conserve nutrients and other minerals, and low biotic diversity. These are species with exponential growth curves, which can settle and disappear quickly from the ecosystem. Knowledge of these attributes is important for the proper understanding and management of ponds.

Figure 10.1 summarises the energy inputs and outputs of prawn ponds. Solar energy mainly controls photosynthesis and water temperature, which directly affects the metabolic rate of the organisms present. Wind promotes the circulation of the mass of water, preventing stratification, increasing gas exchange with the atmosphere and returning nutrients deposited on the bottom to the water column. Organic detritus originates from the intake water and the air (dust, leaves, etc.). The immigrant organ-

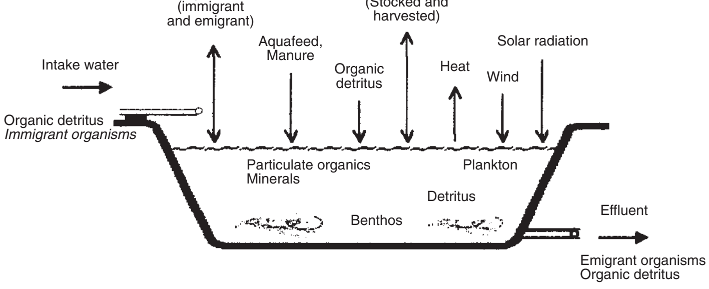

Fig. 10.1 Main energy inputs and outputs in a typical semi-intensive freshwater prawn monoculture pond. Note: aerators, which are used in high-technology semi-intensive systems, are not shown

isms are represented mainly by phytoplankton and zooplankton, fish and insects. These reach the ponds carried by the intake water as cysts, eggs, larvae, juveniles and some adults. They are also dispersed through adherence to the bodies of aquatic birds, and to nets and other equipment, or as the eggs of terrestrial or flying animals with aquatic larvae, mainly insects. Fertilisers, artificial feeds and prawns are introduced by the farmer and their characteristics are discussed in other chapters of this book. Detritus is removed by drainage, which also transports live organisms. Emigration from ponds also occurs through animals that change to the terrestrial or flying adult phase, mainly insects.

The accumulation of a product in an open system, such as a pond, can be represented by the mass balance equation (Piedrahita *et al.* 1984):

$$\text{Accumulation} = \text{Input} - \text{Output} + \text{Transformations}$$

Thus, energy and materials accumulate inside the pond in two forms: as the biomass of living organisms, and as detritus (which may be suspended in the water column or deposited on the bottom). The objective of farming is to accumulate the energy and nutrients in the prawn biomass; this process occurs through biochemical transformations (metabolism), which result in growth.

A simplified food web for freshwater prawn grow-out ponds is presented in Fig. 10.2. The detritus category also includes the feed and organic fertilisers provided by the farmer. Fish are either casual organisms or are introduced by the farmer at a very low density merely to assist in the maintenance of water quality. The top consumers consist of adult prawns, fish and other eventually large predators. Detrital food chains are much more important than grazing food chains in freshwater prawn culture because they play a major role in prawn feeding. Prawns can occupy the second, third or fourth trophic level and their main autochthonous food is benthic organisms (Valenti 1990). When prawns consume aquafeed, they are in the second trophic level. Prawns can only access the constituents of grazing food chains after the latter have died and been incorporated into the detritus category of the food web.

Solar energy, wind, and the addition of chemical fertilisers affect phytoplankton and therefore enter into the grazing food chain, only indirectly affecting the prawns. In contrast, organic fertilisers are incorporated into the detritus food chain and have a direct effect on the prawns. Thus, interventions in the system by the farmer that aim to increase productivity are more effective if they are addressed to the detrital food chain and the development of the benthic community.

Figure 10.3 illustrates the main material inputs and outputs of the pond ecosystem. In dynamic ponds, a pronounced import and export of materi-

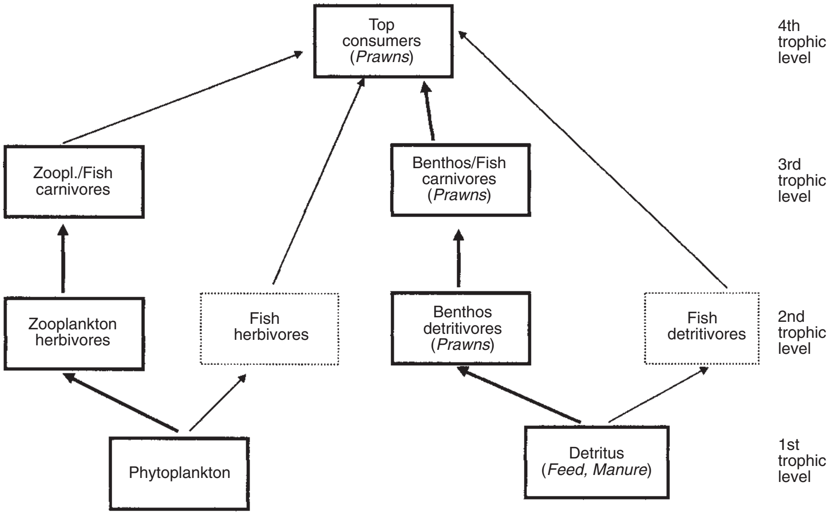

Fig. 10.2 Simplified food web in semi-intensive freshwater prawn monoculture ponds. Notes: wide arrows indicate the intensity of energy flow. Fish are casual or sanitary organisms; hence nekton compartments are shown in dotted boxes

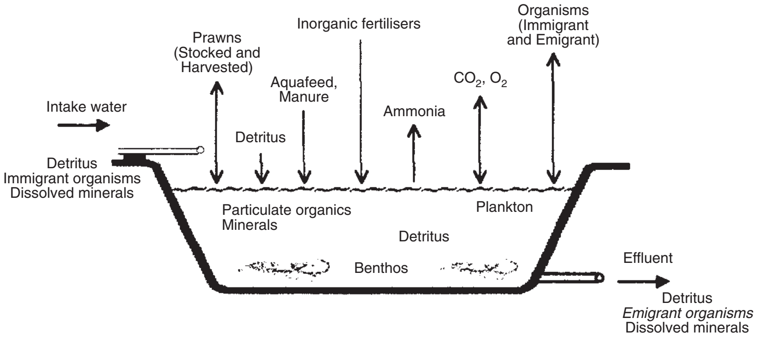

Fig. 10.3 Main inputs and outputs of materials in a typical semi-intensive freshwater prawn monoculture pond

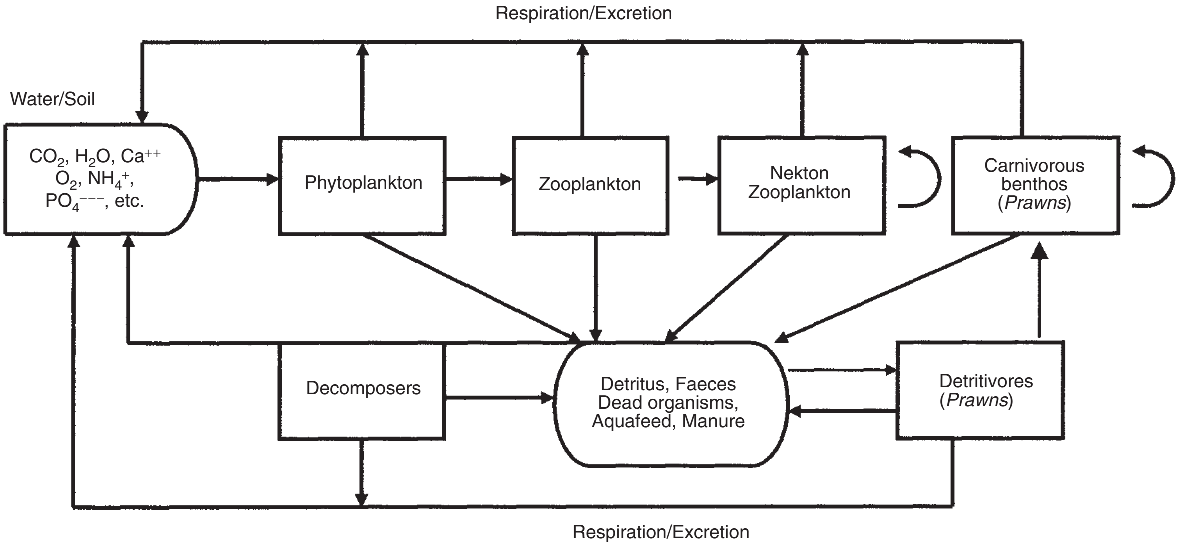

Fig. 10.4 Cycling of materials in semi-intensive freshwater prawn monoculture ponds, presented in a simplified way

als with the adjacent environment generally occurs, because of water exchange. Figure 10.4 presents a simplified diagram of the cycling of materials (including nutrients and other minerals) in the various compartments. The importance of benthic elements for prawns is evident.

The biotic community of the ponds is divided into spatial or functional strata, such as: zooplankton, phytoplankton, nekton, neuston and benthos. Each plays an important role in the function of the system. However, the phytoplankton and benthic strata deserve special attention in freshwater prawn culture.

The importance of phytoplankton is related to the metabolic control of the community, particularly dissolved oxygen (DO_2), pH and water transparency. The concentration of DO_2 and the pH results in a balance between photosynthesis and respiration. Thus, these parameters are extremely influenced by phytoplankton and they exhibit a spatial and temporal stratification in the freshwater prawn ponds (Valenti 1989; Faria 1994). The diurnal variation of these two parameters was studied in generic aquaculture ponds through mathematical models by Piedrahita *et al.* (1984). This analysis revealed that, when the phytoplankton level is very high, DO_2 can reach 14 mg/L in the afternoon and drop to close to zero at daybreak.

The benthic stratum is the most important feature of the pond ecosystem because the prawns, their natural food, and their competitors and predators are in close proximity. There is strong evidence that prawns depend fundamentally on food of autochthonous origin for essential micronutrients (Stahl 1979; Schröeder 1983; Valenti 1990). In addition, benthic organisms play an essential role in the processes of organic matter decomposition. Therefore, prawn pond management mainly concerns the benthic community and detrital food chains.

Ecosystems exhibit mechanisms of internal control which maintain homoeostasis. The stability of resistance is the capacity of an ecosystem to resist external perturbations and maintain its structure and operation intact, while the stability of elasticity is the capacity of restoration after being perturbed (Odum 1985). As ponds are ecosystems in the first developmental stages, they have a low resistance stability because the mechanisms of feedback and substitution are still imperfect. However, they have a high stability of elasticity. This means that grow-out ponds are quite susceptible to perturbations, which can easily alter their structure and operation, but they have a great capacity for recovery.

10.1.3 Farming strategies

Semi-intensive freshwater prawn grow-out in ponds is managed by a 'continuous' or 'batch' process, or combinations of the two systems (New & Singholka 1985; Valenti 1985, 1998b; Cavalcanti *et al.* 1986). Valenti (1995) presented a comprehensive analysis of the effects of these three management systems on the pond ecosystem, and their implications for prawn farming.

The continuous system is characterised by regular post-larval stocking and the culling (selective harvesting) of market-sized prawns. Ponds are not drained and the ecological succession process has time to develop. Hence, more developed seral stages (biotic communities) are established, which contain more prawn predators and competitors (Valenti 1995, 1998b). In addition, incomplete (inefficient) seine harvesting allows remaining large dominant prawns to impact on newly stocked PL, resulting in a lower mean growth rate. The continuous system was developed in Hawaii in the 1970s (Fujimura 1974) and was also introduced into other countries, including Brazil, the French Overseas Territories (Lacroix & Gondouin 1992), Taiwan, and Thailand (New & Singholka 1985) during the 1980s. At that time, the problems of this form of management that have been cited above were not known. The productivity of ponds operated under this system tended to decline with time when ponds were not drained. This resulted in the failure of the Hawaiian prawn farming industry (Malecha 1988) and most Brazilian farms that used this system. It is perhaps fortunate that seasonal problems with water availability caused the strictly continuous method of pond management to become mainly discarded in Thailand.

The batch culture system consists of stocking each pond once, allowing the animals to grow until the medium market size is achieved, and then totally draining and harvesting it. This management system interrupts the ecological succession process before each subsequent stocking. Consequently, the diversity and population density of prawn predators and competitors is diminished. Furthermore, negative intraspecific interactions are much reduced because the dominant prawns are absent at the time of stocking.

The combined system manages both the pond ecological succession and the heterogeneous growth of the prawns (Valenti 1995). Ponds are stocked and cull harvests start when the first prawns attain market size. These precocious prawns are taken out and sold while small ones remain in the ponds for further growth. There is no re-stocking and, after some time (no more than 9 months), ponds are drained and all prawns harvested. This system is principally used in Thailand now, although ponds tend not to be drained until 11 to 12 months after stocking.

The multi-phase strategy includes the use of nursery and intermediate grow-out ponds. These ponds are culled or totally harvested, prawns are graded by size and each homogeneous population is re-stocked. The process of 'stock and harvest' may be scheduled in several ways. However, if ponds are operated for a long time without draining, problems with competitors, predators and growth inhibition caused by the presence of large prawns will certainly occur. Malecha (1983, 1988) described a multi-phase strategy developed for

Hawaii while McGee (1991) described a schedule used in Puerto Rico. More information on multiphase culture is presented in Chapter 8.

10.1.4 Farm design

The semi-intensive batch system can be implemented in several ways, according to the level of technology employed (Valenti 1996, 1998b).

In low-technology semi-intensive systems the rearing ponds are stocked with newly metamorphosed PL (direct stocking) at low densities varying from 4 to 10/m^2. A simple low-cost feed is applied and water quality control is minimal. Only one production cycle per year is achieved and productivity varies between 500 and 1500 kg/ha/yr.

The medium-technology semi-intensive system consists of rearing newly metamorphosed PL in nursery tanks (or ponds) and stocking the grow-out ponds with juveniles at low densities varying from 4 to 10/m^2. A water-stable well-balanced feed is applied and water quality control is more effective. Two cycles of production per year can be achieved and productivity ranges from 1500 to 2500 kg/ha/yr.

The high-technology semi-intensive system is only practical in regions with no restrictions caused by climatic factors and water supply constraints, thus permitting rearing throughout the year. In this rearing system, prawns undergo a two-phase nursery stage before being stocked into grow-out ponds as juveniles at a higher density varying from 12 to 20/m^2. Feed management is rigorous; an aquafeed which supplies all nutritional requirements must be used. Artificial aeration is utilised, and water quality is carefully controlled, with regular monitoring of the main parameters (water transparency, temperature, DO_2, pH and ammonia, as a minimum). Three production cycles per year can be achieved and productivity normally varies between 2500 and 4500 kg/ha/yr, and may attain 5000 kg/ha/yr. Borba *et al.* (1993) described a farm using this system in Brazil in which the annual mean productivity of 110 ponds (0.5 ha each) varied between 3.0 and 4.1 t/ha/yr over a period of 5 years.

According to Valenti (1998b), none of the three semi-intensive technological levels presented is necessarily superior. The choice depends on resources, including climatic conditions, water availability, feed availability, labour capability, and the level of investment available. In practice, high-technology farming has yet to demonstrate its economic feasibility but lower-technology systems are certainly feasible and profitable, if managed properly.

10.2 Operation

Grow-out ponds are operated according to the culture strategy and level of technology adopted. These include: pond preparation; transport of PL and/or juveniles; feeding; the monitoring of water quality, feed consumption, and the growth and health of prawns; harvesting; and pre-processing. Generally, unskilled labourers do these tasks under the supervision of a competent off-site or on-site technician. Small low-technology farms are frequently operated by family labour while large or high-technology farms need a specialised on-site manager. If the low-technology system is used, one labourer is able to take care of 1 to 2 ha of ponds, except during harvesting (New & Singholka 1985). However, for high-technology farms twice as many staff are necessary for the same unit area.

Most published papers on pond management and operation focus on temperate regions, mainly Israel and continental USA. This information is presented in Chapter 11. Scientific papers on tropical *M. rosenbergii* farming are scarce and have generally been published in local languages and journals. Hence, this information is almost completely unavailable for an international audience. The exceptions are the papers on Hawaiian continuous culture which were published during the 1970s and early 1980s. This system of management was described by Fujimura (1974) and updated by Malecha (1983), who included a good review of the literature. According to Griessinger *et al.* (1991), continuous systems were introduced into the French Antilles in 1983 and French Guiana in 1985, whereas discontinuous systems, based on artisanal Thai or intensive Taiwanese systems, were more common in French Polynesia, as well as Israel and in the southern States of the USA. As noted in section 10.1.3, the continuous system was introduced into many other tropical areas, often through the continuing influence of Takuji Fujimura and those who were trained by him. However, Malecha (1988) demonstrated that continuous culture was not suitable for a profitable industry. This section of our chapter will therefore concentrate mainly on pond operation for farms using batch and combined strategies of culture.

10.2.1 Stocking

Parameswaran *et al.* (1992) described the preparation of ponds before stocking in Mauritius; similar management strategy is employed throughout the world. Ponds are drained to remove all predators and competitors, and desilted and dried. Water inlets and outlets are provided with suitable mesh screens to prevent the entry of unwanted animals and the escape of prawns. Pond bottom preparation before filling is discussed in Chapter 14. Commonly, it comprises scraping to remove excess bottom detritus, as well as the application of lime and manure according to the characteristics of the soil and intake water. After that procedure, ponds are filled and stocked with PL or juveniles, according to the culture strategy.

Transport of PL from hatchery to nursery or grow-out ponds was described by New & Singholka (1985) and some experiments focusing on this topic were reviewed by New (1990, 1995). Generally, PL are transported in plastic bags containing one-third water and two-thirds air or oxygen, inserted into insulated Styrofoam™ boxes. Packing densities of 125 to 250 PL/L (of water) permit the transport of animals for up to 16 h. For short journeys (up to 1 h), aerated containers with about 750 PL/L may be used.

Survival during transport depends mainly on DO_2, temperature, PL density, and travelling time. Air or oxygen is normally added to each bag before the journey commences and diffuses into the water during transport. The DO_2 level diminishes with time and animals may become stressed if critical levels are attained. Low temperatures are desirable for successful transport because they decrease prawn metabolism and, as a result, the consumption of oxygen and liberation of ammonia and carbon dioxide are minimised. Water temperatures of 19 to 20°C are recommended (Smith & Wannamaker 1983; Zimmermann 1998). The ambient temperature may be reduced by placing ice near the containers during transport (New & Singholka 1985). Long journeys and high packing densities decrease prawn survival rates.

Experiments performed by Alias & Siraj (1988) and Vadhyar *et al.* (1992) suggested that it is possible to pack up to 300 PL/L for 12-hour journeys and maintain survival close to 90%. For journeys of 24 to 36 h, survival rates decrease (Alias & Siraj 1988) and a packing density of 100 PL/L is normally used (New 1995). Smith & Wannamaker (1983) performed several experiments on the transport of *M. rosenbergii*. The results indicated that PL could be transported in polyethylene boxes, in densities lower than 180 PL/m^2 for 48 h with 90% survival. According to these authors, the use of brackishwater (2–8 p.p.t.) or added substrates is not beneficial. On the other hand, data obtained by Alias & Siraj (1988) suggested that substrates may increase survival in 18-hour journeys, even at such low packing densities as 100 PL/L.

The transport of juveniles within small medium-technology farms normally occurs in polyethylene or metal containers. Large farms use truck-based aerated transport tanks. Wild-caught juveniles are often used for stocking purposes in countries such as Bangladesh and India (Chapter 17). Their purchase from other farms or from hatcheries or specialised nurseries is uncommon, but has been reported to occur in Brazil (Valenti 1993). In this latter country, juveniles (1.5 g) are transported from the hatchery to the farm in 200 L aerated polyethylene vats, packed at 10/L for 12 h or at 5/L for up to 36 h (Zimmermann 1998). Palm leaves are added as substrate in order to decrease stress.

Valenti (1995, 1996) recommended that ponds should be stocked as soon as possible after they are filled with water, to avoid colonisation by competitors and predators. Experiments performed by Cavalcanti & Rodrigues (1998) corroborate this strategy. These authors stocked pens situated within ponds with a high density of PL (78/m^2). It was observed that PL stocked 30 days later than ponds were filled resulted in a mean survival rate of 33% after 2 months, while those stocked in similar ponds 7 days after filling showed a mean survival rate of 66%. This result was very close to the survival obtained in pens which were covered by a screen to avoid the entrance of insects, and stocked 30 days after filling.

The acclimation of PL or juveniles to the temperature and pH of the pond water is important to avoid stress or death. Thermal and pH shock may cause severe mortality. Containers (bags or boxes) are floated in the pond for 15 to 30 min to equalise temperature (New & Singholka 1985;

Zimmermann 1998). Valenti (1996) recommended a slow exchange of water between the containers and the pond until the differences become less than 1°C and 0.5 pH units, following which prawns are released into the pond. On the other hand, Sarver *et al.* (1982) suggested acclimating PL to pond pH while still in the hatchery.

Medium- and high-technology farms stock juveniles in grow-out ponds instead of PL. Normally, juveniles are produced in in-farm nurseries. Experiments carried out in temperate regions have demonstrated that grading juveniles by size increases productivity (see Chapter 11). Malecha (1988) pointed out that it is more profitable to discard stunted juveniles and to use only the fast-growing fraction of the population to stock grow-out ponds. The effects of size-grading juveniles on production and profit still need to be better investigated in tropical regions.

Stocking density in grow-out ponds varies according to the farm design (see section 10.1.4). Generally, a density of 5 to 20 PL/m^2 is used in tropical areas (Lee & Wickens 1992). Density has a major effect on prawn growth and a minor effect on survival (Valenti 1989). Usually, high stocking density (close to 20/m^2) is associated with a high production of small prawns while low stocking densities lead to the production of large prawns with low productivity. Results obtained in a sub-tropical zone by Willis & Berrigan (1977) clearly demonstrated this observation.

10.2.2 Monitoring

The correct monitoring of various characteristics of the ponds enables farm operators to detect problems before they prejudice production. It is important to check regularly pond structures, water flow, the presence of weeds, water quality, feed consumption, and the growth and health of prawns, for example. The frequency and accuracy of monitoring depends on farm design.

Valenti (1996) and Zimmermann (1998) recommended a periodic inspection of all physical pond structures. These inspections include mechanical filters, bunds, inlet and outlet channels and pipes, and monks and screens. The flow and level of water need to be checked daily and corrected if necessary. Any decrease in water level diminishes the effective area available to the prawns because the bunds are sloping. Generally, the water column is maintained at 0.8 to 1.0 m deep (New & Singholka 1985; Valenti 1985; Lee & Wickins 1992). However, satisfactory results were obtained by Mendes & Marins (1995) in experimental earthen ponds which were only 0.3 to 0.4 m deep. Problems with temperature variation were not observed because the experiment was performed in a region where the diurnal variation is minimal. However, there was a high development of algal growth.

Weeds may colonise shallow areas of the pond bottom and bunds as a consequence of the ecological succession process. As they are pioneer species (r-strategists), their growth may rapidly fill a significant part of the pond. In addition, vegetation established along the pond banks to minimise erosion may grow excessively and colonise the inner portion of the pond bund. Submerged plants provide food and shelter for prawns, but prevent efficient harvests (New & Singholka 1985). In addition, they retain sediment and die rapidly, which reduces water quality and provides conditions which favour the development of rooted plants (Valenti 1996). Floating weeds greatly increase the loss of water by evapotranspiration.

Valenti (1996) recommended the continuous monitoring and control of weeds. New & Singholka (1985) stated that this task is very time and labour consuming, but it can be diminished if the pond has been well constructed and is well managed. This implies the construction of ponds without shallow areas, avoiding long periods when ponds are empty or have low water levels, maintaining an adequate phytoplankton population to shade the bottom of the ponds, and cutting the vegetation on emergence. Zimmermann (1998) presented some chemical and biological means of controlling weeds in freshwater prawn ponds, using herbicides and herbivorous fish in low densities.

Detailed information on water quality for grow-out ponds is presented in Chapter 14. The main parameters which are monitored by farmers are temperature, water transparency, DO$_2$, pH, ammonia, hardness and alkalinity. The frequency and accuracy of monitoring depends on farm design (see section 10.1.4). Low-technology farms generally only monitor temperature and transparency weekly, using simple devices such as a mercury thermometer and a Secchi disc. From time to time, they also perform a more complete examination, which includes measuring the levels of DO_2 and pH. Medium-technology farms generally monitor temperature, transparency, pH and DO_2, either daily or twice per week. High-technology farms check these parameters daily, and ammonia, alkalinity and hardness weekly or fortnightly. In these farms, aerators are turned on when the DO_2 level is low or when temperature or DO_2 stratification is detected. Rogers & Fast (1988) described stratification in freshwater prawn ponds in Hawaii and suggested that this phenomenon increases heterogeneity in prawn size and decreases feed intake, growth rate and production.

Farmers generally feed prawns once or twice daily, using a balanced ration and quantities proportional to the prawn biomass. The monitoring of feed consumption is practised mainly in medium- and high-technology farms. Low-technology farmers frequently neglect such observations and sometimes have problems with oxygen depletion. New & Singholka (1985) recommended that feed consumption should be controlled depending on the quantity of food that was observed to be left in the pond on the following day. Zimmermann (1998) suggested feeding prawns on trays to facilitate the control of consumption. Valenti (1996) recommended reducing the feeding rate by 50% if the DO_2 level falls lower than 3.5 mg/L in the early morning or if the temperature falls to the 20 to 24°C range during the day. This author suggested that feeding should cease if the DO_2 falls lower than 2.0 mg/L or the temperature falls below 18°C. Feeds and feeding management are discussed in detail in Chapter 13.

The growth and health of prawns are monitored by means of samples collected periodically from the ponds. Prawns are measured and weighed and their exoskeleton and gills are checked for the presence of parasites or epibionts (see Chapter 15). These samples are also used to calculate the quantity of feed which will be offered to prawns during the next period. Valenti (1985, 1996) suggested that sampling should occur at monthly intervals.

New & Singholka (1985) strongly recommended that farmers should keep adequate written records containing data on stocking, feeding rate, water quality and all other parameters monitored. This practice enables consistent evaluation of management. Andrade & Uliana (1998) presented two comprehensive record sheets to help farmers achieve this goal. These sheets include space for recording data on stocking, growth rate, feeding, harvesting, and the application of fertilisers and lime, among other factors. These authors also discussed the general management of freshwater prawn farms, including their relationship with other farms and the establishment of co-operatives and farmers associations.

10.2.3 Control of predators and competitors

Several types of organisms colonise ponds as soon as they are filled, as a consequence of ecological succession. These species are r-strategists and therefore have a great capacity to expand rapidly. Most are beneficial to prawns, such as nearly all plankton components, part of the benthos and various micro-organisms. However, there are several animals which compete with and/or predate on prawns. Most of these are naturally adapted to pond conditions and, hence, have a competitive advantage on the prawns introduced by man.

Interspecific competition is mainly for space, food and DO_2. Associated fauna compete with prawns for habitats and shelters. In addition, they compete for pelleted feed and for grazing on the benthic stratum. Competition for food and space may produce agonistic behaviour. The energy spent as a consequence of competition may reduce growth and therefore productivity. Dissolved oxygen is a major factor which limits the increase of biomass in aquaculture. Hence, a large biomass of associated organisms decreases the carrying capacity for prawns.

Several components of the pond biotic community are carnivorous species which may predate on prawns, mainly during the first phases when PL are very small. Predators may cause mortality by eating prawns or causing injuries to their bodies and legs which facilitate the establishment of diseases. In addition, the energy spent by prawns in escaping from predators certainly reduces growth (Lombardi 1998).

Prawns may assume successive trophic levels as they grow (Fig. 10.2). Consequently, many organisms, which are competitors and predators during prawn stocking and the first months of culture, later become their preys. Prawns can adjust to differences in diet quality by increasing their consumption of benthic fauna (Hill *et al*. 1997). Therefore, management strategies which aim at increasing natural productivity, such as the application of low-cost fertilisers, may decrease feeding costs (MacLean *et al.* 1989; Hill *et al.* 1997). However, this strategy may also increase the population of competitors and predators. Hence, a better understanding of the role of pond fauna, as competitors, predators or food items, could lead to management strategies which selectively enhance desirable food organisms and eliminate the others in each phase of culture (Valenti 1995). In conclusion, more comprehensive knowledge about the ecological succession process and its management may improve productivity and profit. It certainly provides an important avenue for new research work.

Prawn predators may be separated into two groups: the animals which are components of the pond biotic communities and those that casually enter the ponds from adjacent terrestrial environments or are transported by intake water. The first group mostly consists of insects of the Orders Odonata (dragonflies), Coleoptera (beetles), and Heteroptera (water fleas), and some fish. The second includes large fish (which reach the pond as larvae or eggs), amphibians, and reptiles, as well as sub-aquatic birds and mammals. Lombardi (1998) presented a comprehensive review of predation in freshwater prawn ponds in Brazil. This comprised long lists of species and mechanisms of control. The specific composition of pond fauna depends on the geographical location of the farm, but the main taxonomic groups are similar around the world.

The entry of fish and some insects may be controlled by passing the intake water through suitable screens or gravel filters (New & Singholka 1985; Valenti 1985; Lombardi 1998). Most commercial prawn farms rely on simple net filters. However, some use gravel filters in their intake system. Lombardi (1998) described an interesting and efficient retro-washed gravel filter that is inserted before the inlet pipes for each pond. Figure 10.5 shows a model combining a sequence of different mesh screens set up before the gravel bed. The efficiency of all of these structures is quite variable and differs according to the characteristics of the various predators. Normally, insects (mainly dragonflies), carnivorous fish and birds are the most serious predators in freshwater prawn farming.

Air-breathing insects may be controlled by the addition of diesel mixtures on the pond surface 1 week before stocking (Johnson 1982; MacLean *et al.* 1989). Chemicals may be used to kill dragonflies and other insects but Valenti (1995) stated that this practice may alter pond ecosystems in a negative way for prawns. The stocking of fish of the family Poecilidae (e.g. *Gambusia affinis*) is sometimes used to control insects (New & Singholka 1985; Cavalcanti *et al.* 1986). Fish can be effectively

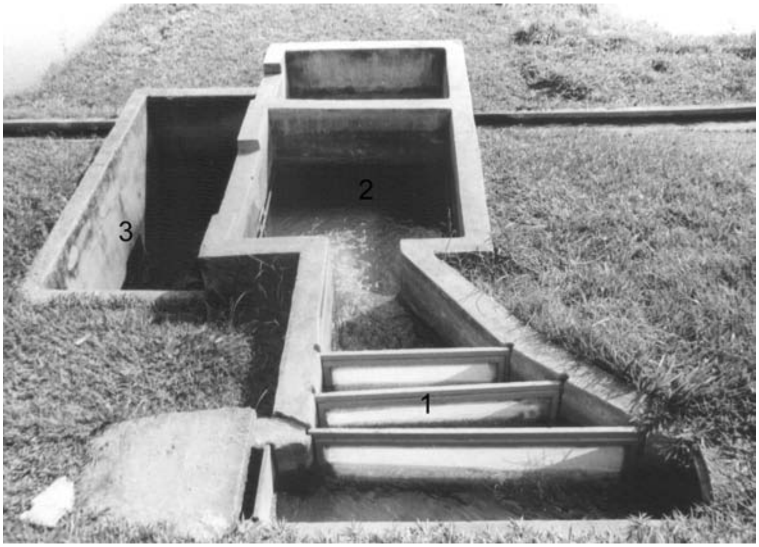

Fig. 10.5 Structure for predator and competitor control

Key: 1 = sequence of different mesh screens; 2 = gravel bed; 3 = lateral chamber used to wash gravel to avoid clogging.

controlled by using rotenone (Cavalcanti *et al.* 1986), which kills fish but has no effect on prawns at low concentrations. However, in some countries (e.g. Brazil), the use of rotenone is prohibited by law because of environmental concerns. Small fences around ponds (0.6 m high) are used in Thailand to prevent the entrance of catfish (*Clarias batrachus* and *Mystus planiceps*) and snakehead fish (*Ophiocephalus micropites* and *O. striatus*) (New & Singholka 1985). These fences may also prevent the entrance of amphibians, reptiles and some mammals (Lombardi 1998). Birds are very difficult to repel or control (Johnson 1982). Nets or strings stretched over the ponds, bird-scaring devices and explosives may help to deter birds (New & Singholka 1985; Cavalcanti *et al.* 1986). Lombardi (1998) recommended the use of dogs and stated that this is a cheaper and more efficient way to repel birds.

Competent management of prawn competitors and predators includes early stocking (as soon as the pond is filled), periodic seining, and totally draining the ponds at least once per year. Prawns have a great advantage over competitors and predators if they are placed in the ponds at the beginning of the colonisation process (Valenti 1995). At this moment they have time to adapt to the new habitat and to grow before competition and predation become very intense. Cavalcanti & Rodrigues (1998) observed that *M. rosenbergii* PL can control the dragonfly population and reduce their density by an order of five to six, if they are stocked before the insects hatch. Seining can remove large predators, such as fish, turtles and snakes, and can be practised during selective harvesting. Total draining removes all competitors and predators and interrupts community development, thus avoiding an increase in the standing stock and the diversification of the associated fauna (Valenti 1995).

10.2.4 Harvesting

Harvesting techniques comprise seining or draining, or a combination of the two. Seining is used for cull harvesting while draining is employed for total harvesting (New & Singholka 1985; Lee & Wickins 1992; New 1995). The choice of a particular technique depends on the type of farm management. The effect of the various forms of harvesting on prawn population, the pond ecosystem and yield have been noted in other sections of this chapter (see also Chapter 16). This section therefore only describes each harvesting procedure without further comment.

Seining consists of extending a net across the pond and drawing it along the bunds by four to six personnel. The prawns are then removed from the net at one end of the pond. New & Singholka (1985) described seining operations and net characteristics in detail. Generally, seines are made with monofilament nylon, and provided with floaters, sinkers and a bag. Dimensions are quite variable. Valenti (1996) recommended the use of 2.5 m high nets with a length equivalent to 1.6 times the pond width. The mesh size is adjusted to catch the prawn size demanded by the market and varies from 18 to 50 mm between knot stretched mesh.

Drain harvesting is performed by emptying the pond by gravity or by means of pumps. Prawns are caught in sumps (Fig. 10.6) positioned before, after, or even within the monk, or in net bags or net enclosures outside the ponds (New & Singholka 1985; Lee & Wickins 1992). Some farmers introduce a continuous flow of clean water in the sumps during harvesting to avoid prawn stress.

Special attention during harvesting procedures is necessary to avoid 'mushiness' (see Chapters 18 and 19). Valenti (1996) particularly stressed that all harvested prawns must be immediately washed with clean water, killed in a mixture of water and ice at 0°C, and then washed in a solution of chlorine (5 mg/L). This simple practice is essential to prevent 'mushiness' and preserves product quality. However, it must be carried out near the pond, on the bund; transporting live prawns to processing facilities before this treatment is carried out is unsuitable because some prawns will die during transport and develop the 'mushiness' (Valenti 1998a). Therefore, it is important to consider this pre-processing technique as a part of the harvesting procedure.

New & Singholka (1985) recommended that harvesting should commence very early in the morning when the temperature is lower, to preserve the quality of prawns harvested. However, harvesting at night is not recommended, except for specialised marketing. Joseph *et al.* (1992) observed that catching prawns at night increases the proportion of soft-

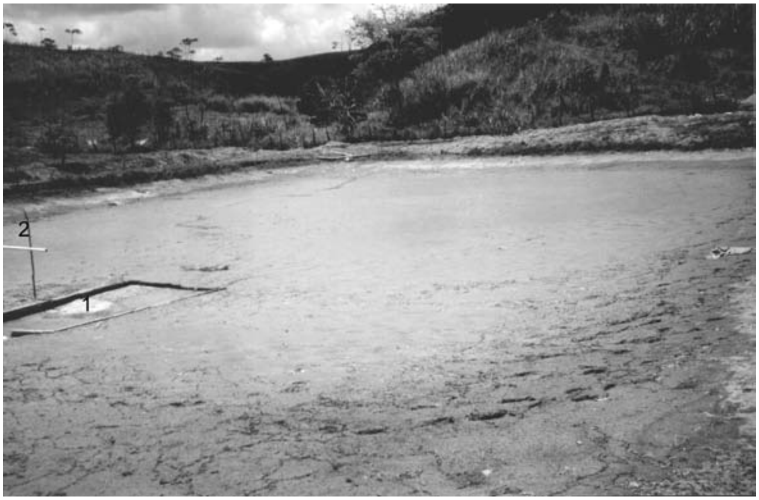

Fig. 10.6 Pond basin after draining harvest

Key: 1 = sump; 2 = pipe transporting clean water to sump during harvest.

shelled animals. This phenomenon may increase or decrease the crop value, depending on the target market.

Very little research on harvesting techniques has been carried out. Some improvements have been suggested, such as mechanical harvesting (Williamson & Wang 1982; Losordo *et al.* 1986) but there is little, if any, commercial application of these procedures (New 1995).

10.3 Prawn growth and survival

Growth is the result of a balance between the processes of anabolism and catabolism which occur in each individual (von Bertalanffy 1938). It can be expressed as the increase in length, volume or weight against time (Hartnoll 1982). In aquaculture, growth is generally measured by weight gain. Some authors have developed equations to relate data on length and weight for *M. rosenbergii* raised in tropical and sub-tropical ponds (Menasveta & Piyatiratitivokul 1982; Sampaio & Valenti 1996; Valenti & Sampaio 1996). As an example, the equation presented by Sampaio & Valenti (1996), based on data obtained in four experimental ponds, was as follows:

$$W = 1.21 \times 10^{-6}\ L^{3.43}$$

where:

W = weight (g); and
L = length (mm).

In animals with a rigid exoskeleton, as is the case for crustaceans, growth is an essentially discontinuous process. There is a succession of moults separated by intermoult periods; almost all external growth occurs immediately after a moult, before the hardening of the new exoskeleton. After this phase, only limited growth can occur due to the flexibility of the membranes which join the plates forming the rigid skeleton (Mauchline 1977; Hartnoll 1982). In addition, *M. rosenbergii* exhibits a more complex growth pattern called 'leapfrogging', which is detailed in Chapter 16. In the current chapter, growth is treated in a simplified way, from a farmer's perspective, namely the mean increase in prawn size within the ponds.

The growth of any organism depends both on intrinsic factors typical to the genetic constitution of each population, and on extrinsic (environmental) factors acting on the individual throughout its ontogenetic development. According to Hartnoll (1982), the exogenous factors which most interfere with crustacean growth are temperature and food availability. For prawn populations reared in semi-intensive grow-out ponds, density also plays a major role.

Genetic manipulation may increase growth. Studies conducted by Meewap *et al.* (1994) indicated that parental and maternal characteristics have a great effect on the growth of *M. rosenbergii*. In an earlier paper, Doyle *et al.* (1983) demonstrated that the selection of early maturing female prawns for hatchery use may improve the genetic base for enhanced growth. Variability in temperature-related growth has been observed in populations from different geographic locations (Sarver *et al.* 1979) and intraspecific hybrids of *M. rosenbergii* races have demonstrated improved growth rates (Dobkin & Bailey 1979). However, no selected varieties or hybrids had become available to farmers by the year 2000. Genetic improvement is an important avenue for future research.

Temperature strongly affects prawn metabolism, influencing DO_2 consumption and feed intake. According to Farmanfarmaian & Moore (1978), who were considering the possible use of thermally enhanced waters (e.g. geothermal), growth nearly doubles for every 5°C increase within the 20 to 30°C range. However, mean temperature is determined by the environmental conditions which pertain where the ponds are constructed; in practice, commercial farmers have little control over this factor once the farm site is selected. Early attempts at rearing freshwater prawns in artificially heated water in the UK proved uneconomic, due to the cost of energy. In contrast, commercial prawn culture which indirectly uses thermal waters is currently being practised in New Zealand (see Chapter 17).

Growth depends on both the quality and quantity of feed available. The amount of feed supplied to the prawns raised in semi-intensive systems is generally abundant and sufficient. However, there are indications that *M. rosenbergii* fundamentally depends on the natural food present in ponds (Corbin *et al.* 1983; Schröeder 1983; Lilyestrom *et al.* 1987; Valenti 1990). If this is so, increased competition for natural food would occur at higher densities, regardless of the amount of ration provided. Growth is also affected by water quality and perhaps by inter-relationships between the ionic composition of water and aquafeeds. For example, the influence of dietary calcium and water hardness has been investigated by Zimmermann *et al.* (1994) and is discussed in Chapter 13.

The effect of population density on growth is manifested through competition and other forms of interaction amongst animals. With increasing population density there will be an increase in intraspecific competition for resources, for example food and space. When one of these resources becomes insufficient, it will turn into a limiting factor. Growth will possibly be reduced both because of the lack of this resource and because of the greater energy expenditure caused by competition stress.

Macrobrachium rosenbergii is territorial to some degree and exhibits aggressive and social behaviour (Peebles 1979a,b; Karplus *et al.* 1992). The greater energy expenditure due to the dispute for a territory and its defence at higher densities may reduce growth rate. Although competition is usually associated with limited resources, it is known that dominance and territoriality may limit access to available resources, even in rich environments (Peebles 1979a). In addition, in the presence of aggressiveness among competitors, stress is intense even when food is abundant (Krebs 1972). Social suppression of growth in *M. rosenbergii* has been demonstrated by laboratory studies (Karplus *et al.* 1992). This subject is detailed in Chapter 16.

The effect of population density on the average weight of *M. rosenbergii* at the time of harvest is well known; however, most published papers focus on temperate regions. Studies involving an overall evaluation of growth during culture under semi-intensive conditions are scarce. Valenti *et al.* (1993) determined the variation of growth rate in experimental ponds managed according to the low-technology semi-intensive system. These authors observed a significant reduction in specific growth rate when population density increased from $4/m^2$ to $20/m^2$. The effect was most marked in the range of $4/m^2$ to $12/m^2$ but was less noticeable from $12/m^2$ to $20/m^2$. The results obtained by Sampaio & Valenti (1996) confirmed this tendency and indicated that the effect of density on the growth of this species is marked, even when population density varies within a small range (<1 individual/m^2).

Quantifying growth is important in aquaculture since this is one of the major factors determining productivity. For both theoretical and practical applications, it is useful to express growth by means of mathematical models which describe it in a general manner, as has long been practised in fishery studies (Beverton & Holt 1957; Bagenal

1978; Pauly 1980). In aquaculture, however, only the data referring to stocking and harvesting are usually used for analysis, without considering the growth which occurs between these events, although periodic estimates of animal size are commonly made. Thus, all the information contained in intermediate data is lost. Hopkins (1992) stated that the use of mathematical models in aquaculture should be encouraged, since it represents the most precise and complete way of analysing growth data. In the case of crustaceans, growth curves represent a summation of the discontinuous growth processes in a continuous form.

Growth curves facilitate forecasting and may be used in the determination of production models. Some papers have been published using the von Bertalanffy equation (von Bertalanffy 1938) to represent the growth of *M. rosenbergii* under batch culture conditions (Valenti *et al.* 1993; Faria & Valenti 1995; Sampaio & Valenti 1996; Valenti & Sampaio 1996). Guest (1979) used the same model to represent the growth of *M. amazonicum* in the laboratory. In all of these studies, the adjusted equations fit very well to obtained data. Figure 10.7 shows an example of these curves, which indicate that growth rate is high during the first months after stocking and decreases later.

The main causes of mortality in grow-out ponds are predation, intraspecific aggressiveness, and the effect of adverse water quality parameters (Peebles 1978; New & Singholka 1985; Valenti 1990). The incidence of mortalities caused by diseases, parasites and poor nutrition is uncommon in well-managed semi-intensive culture (Valenti 1990). In addition, the effect of population density on survival is very much lower than its effect on growth (Valenti 1989). Predation has already been discussed in section 10.2.3. Intraspecific mortalities are related to the moult cycle and differences in prawn size (Peebles 1978). Postmoult animals are attacked while their exoskeleton is soft by intermoult prawns. The frequency of death increases in relation to the relative size of the aggressor and its victim. Chapter 16 presents some other considerations concerning *M. rosenbergii* agonistic interactions. In tropical and sub-tropical regions, depletion of DO_2 is the principal environmental factor causing mortality. Sudden decrease in water temperature may also be an important factor in sub-tropical areas.

In semi-intensive batch culture, survival generally varies between 50 and 80% at the end of 6 to 8 months (Lee & Wickins 1992; Valenti 1996). A survival rate above 50% between stocking and total harvesting has been considered acceptable by New & Singholka (1985) and Valenti (1990). According to Fujimura (1974) and Malecha (1983), survival in continuous culture systems is about 50 to 60%.

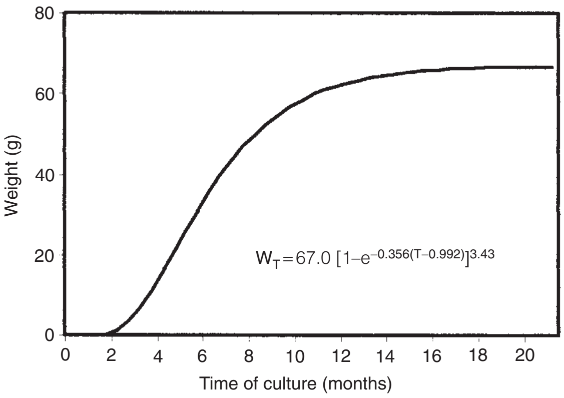

Fig. 10.7 Growth curve of *Macrobrachium rosenbergii* in a rearing pond obtained by means of a von Bertalanffy model. (Source: Sampaio & Valenti, 1996.)

Key: W_T = mean weight of prawns at time T; e = natural logarithmic base.

10.4 Production models and productivity

The prawn biomass in a pond at any moment results from a balance between increase in weight and the mortality of the stocked individuals. Therefore, if there is no re-stocking during the culture period, the biomass variation as a function of time will be represented by a curve with a maximum point (Valenti 1990). This corresponds to the maximum production obtained under these specific grow-out conditions (Fig. 10.8). The biomass curve may be represented by the equation:

$$B_T = N_O\, S_T\, W_T$$

where:

B_T = prawn biomass inside pond at time T;
N_O = number of prawns stocked;
S_T = survival rate at time T; and
W_T = mean weight of prawns at time T.

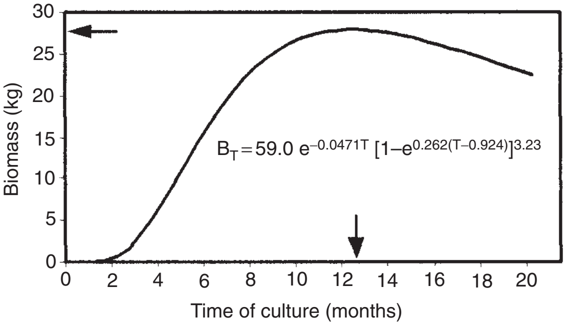

Fig. 10.8 Biomass curve representing the variation of total weight of prawns in a pond against time. Note: arrows indicate maximum biomass and the moment of maximum biomass achievement. (Source: data obtained in an experimental pond at São Paulo State University, Brazil [Faria & Valenti 1995].)

Key: B_T = prawn biomass at time T; e = natural logarithmic base.

Variation in survival and growth during culture may be expressed by mathematical models similar to those used in fisheries studies. Substituting these equations in the biomass formula above, it is possible to obtain useful models to describe the variation in prawn biomass (pond production) which occurs in ponds during rearing. Biomass curves were obtained by Valenti (1989), Faria & Valenti (1995), and Valenti & Sampaio (1996) in experimental batch cultures of *M. rosenbergii* performed in Brazil. These authors used mathematical equations to calculate the maximum biomass and the time in which it would be attained. Such equations assist in forecasting productivity and making the decision about the best moment for total harvest. In the case of the model tested by Faria & Valenti (1995), the difference between the actual and forecast harvest was within 4 to 21% of the forecast prawn biomass in all ponds. Gibson & Wang (1979), who developed a model aimed at managing the continuous prawn culture system in Hawaii, stated that modelling may be a more accurate means of management than the use of data obtained by sampling prawns. Other models for managing the Hawaiian continuous culture system were developed by Huang *et al.* (1976) and Polovina & Brown (1978).

Productivity is a function of the culture system and the farming strategy and level of technology practised, as was discussed in earlier sections of this chapter. In addition, pond productivity may vary according to pond age, size and location. Generally, older and smaller ponds are more productive (Malecha 1983). Pond location affects productivity from a climatic point of view, mainly through temperature. In tropical and sub-tropical areas, the mean productivity of semi-intensive culture systems is regularly between 1000 and 3000 kg/ha/yr (Malecha 1983, 1988; Shang 1982; Wulff 1982; Lacroix & Gondouin 1992; Valenti 1993, 1998a; New 1995). However, it can reach as high as 4000 to 5000 kg/ha/yr (Hsieh *et al.* 1989; Borba *et al.* 1993). Increasing stocking density normally increases productivity, but decreases prawn size at harvest (New & Singholka 1985).

10.5 Environmental protection

Freshwater prawn farming is recognised as an efficient way of producing crustaceans with minimal environmental impact (Chapter 23). Until today (2000), there is no published information which indicates that there are any negative effects on the environment produced by the farming of *M. rosenbergii*. Despite this, the concept of responsible aquaculture needs recognition by scientists and farmers alike; guidelines designed to facilitate this have been published by the FAO (1997a). Two matters of environmental concern need particularly careful attention, namely the escape of prawns from grow-out ponds and the discharge of polluted effluents into natural waters.

Macrobrachium rosenbergii is an exotic species in most of the countries where it is farmed. Other *Macrobrachium* spp. may also be introduced where they are not indigenous. For example, the introduction of *M. malcolmsonii* into China is currently (2000) being contemplated. In such cases the escape of prawns into natural waters may result in the establishment of a new species within the environment. This may cause a negative ecological impact in two ways, namely the dissemination of pathogens and the establishment of an exotic population which may affect native species (competition, predation, etc.). In all cases where introductions are contemplated, the precautionary approach should be applied (FAO 1997b). Though adult prawns may be observed following escapes from inland farms, it is unlikely that *M. rosenbergii* could colonise a new habitat unless it escapes from farms situated near to the coast because its larval phase takes place in estuarine waters.

There are no reports of any dissemination of pathogenic micro-organisms by the introduction of *M. rosenbergii*. However, there are some reports of the establishment of populations of this species in natural habitats in South America. Pereira *et al*. (1996) described the founding of an *M. rosenbergii* population in natural waters in Venezuela. No negative effects on the environment had been observed at that time but these authors speculated that some type of impact might occur in the future. In Brazil, there are reports of populations colonising natural waters in the States of Espírito Santo (J. Centoducate, pers. comm. 1999) and Pará (P. Moraes-Riodades, pers. comm. 1999). Both populations are being artisanally fished and no adverse effect on the environment has been observed so far.

Farmers have a responsibility to prevent the escape of animals from their impoundments. However, this obligation has been neglected by almost all producers around the world. We suggest that constructing a 'security tank' to receive the water drained from the monks before it is discarded may help to solve this problem. Such tanks would need to be provided with suitable screens to prevent the escape of prawns. In addition, special care during harvesting is important. Methods of preventing the escape of prawns from grow-out ponds, the disinfection of effluent waters, and the potential ecological impacts of *M. rosenbergii* are all important fields that need research.

The organic residues produced as a consequence of unconsumed feed and the residual fertilisers may be important pollutants. In general, pond effluents are rich in nitrogenous compounds, phosphates and solid particles (Valenti 1996). The establishment of a suitable feeding and fertilising schedule, as well as the use of a stable aquafeed with a good feed conversion ratio (FCR) (see Chapter 13), may diminish this kind of pollution. The effluents from prawn farming may be used for irrigating crop production, as recommended by Valenti (1996). The integration of freshwater prawn farming and agriculture is discussed in Chapter 12.

10.6 References

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11
Grow-out Systems – Culture in Temperate Zones

James H. Tidwell and Louis R. D'Abramo

The majority of research and development efforts concerning freshwater prawn farming has been conducted in tropical regions. However, activities in temperate regions also date back several decades. Culture of *Macrobrachium* in temperate zones offers positive opportunities, despite the inability to culture year-round. Unique problems imposed by a restricted growing season must be addressed, and opportunities capitalised on, to attain commercially viable production in these regions.

11.1 Culture in temperate zones: problems and opportunities

11.1.1 Problems

Compared to tropical environments where culture throughout the year is possible, the growing season for prawns in temperate zones is limited to 100 to 150 days. This growing period is defined by low water temperatures during the period prior to stocking and after harvest. This situation creates at least a potential for crop loss, due to an unanticipated temperature decrease during the period soon after stocking or just prior to harvest. However, such losses are rare, and experienced producers can normally achieve maximum growth without incurring undue risks. Production in temperate climates is generally limited to the practice of batch culture, i.e. a single stocking and a total harvest prior to reaching lethally low water temperature.

Successful culture in temperate climates requires special considerations at both stocking and harvest. At stocking, it is essential that juveniles of the proper size and number all be available at the same time so that the maximum number of days in the production (grow-out) ponds can be realised. Also, the fewer the number of available production days, the greater the importance of stocking nursed juveniles of appropriate size (weight) rather than new postlarvae (PL). In the central USA, pond water temperatures are suitable for approximately 120 to 140 days in production ponds. To achieve marketable sizes of >20–30 g within that period of time requires a sufficient supply of juveniles of approximately 0.3 to 0.5 g mean individual weight to stock production ponds at 60 000 to 100 000 juveniles/ha. This recommended stocking size/weight imposes a requirement of 45 to 60 days of nursery culture after the post-larval stage. This need for a local nursery facility can potentially impair the growth of a regional industry.

Seasonal availability of the final marketable product is another potential problem imposed by production in temperate regions. Marketable-sized prawns can only be harvested during a 4- to 8-week period, depending on growth. Also, the need to batch-harvest ponds completely in the autumn can 'flood' markets with fresh or live product over a relatively short period of time.

11.1.2 Opportunities

Macrobrachium rosenbergii inhabits freshwater for most of its life cycle. Hence, production can occur much farther inland than is normally feasible with penaeid species (marine shrimp). Production in temperate regions offers the opportunity for prawns to be produced in close proximity to large inland urban markets and for producers to supply these markets with unique product forms, such as fresh or live product. These product forms are especially important for fulfilling the demand of special niche markets, such as the large ethnic communities found in many of these urban areas.

Temperate conditions also create unique production options. For example, in the Midwest region of the USA, prawn producers raise rainbow trout (*Oncorhynchus mykiss*) during the winter in prawn ponds as part of a seasonal rotation (Tidwell *et al.* 1991). Prawns have also been successfully intercropped with another crustacean species, the red swamp crawfish, *Procambarus clarkii* (D'Abramo *et al.* 1997) (Fig. 11.1). The limited growing season has also created interest in evaluating the potential of polyculture with species previously thought incompatible. Researchers at Kentucky State University are currently evaluating the polyculture of yellow perch (*Perca flavescens*), a coolwater finfish, in cages suspended in prawn ponds (S. Coyle, pers. comm. 1999).

11.2 Temperate production cycle

11.2.1 Broodstock

Temperate climates warrant the collection of broodstock from ponds before water temperatures become lethally low. Broodstock are then held in temperature-controlled buildings for the subsequent production of larvae. The protocols for collection, holding, and feeding of broodstock are provided in Chapter 4. Maturation, mating, and spawning of eggs occurs without the need to adhere to special lighting conditions or photoperiod manipulation if water temperatures are kept above 22°C, and populations are held in the proper male : female ratio, namely 2 to 3 males per 10 females (D'Abramo *et al.* 1995).

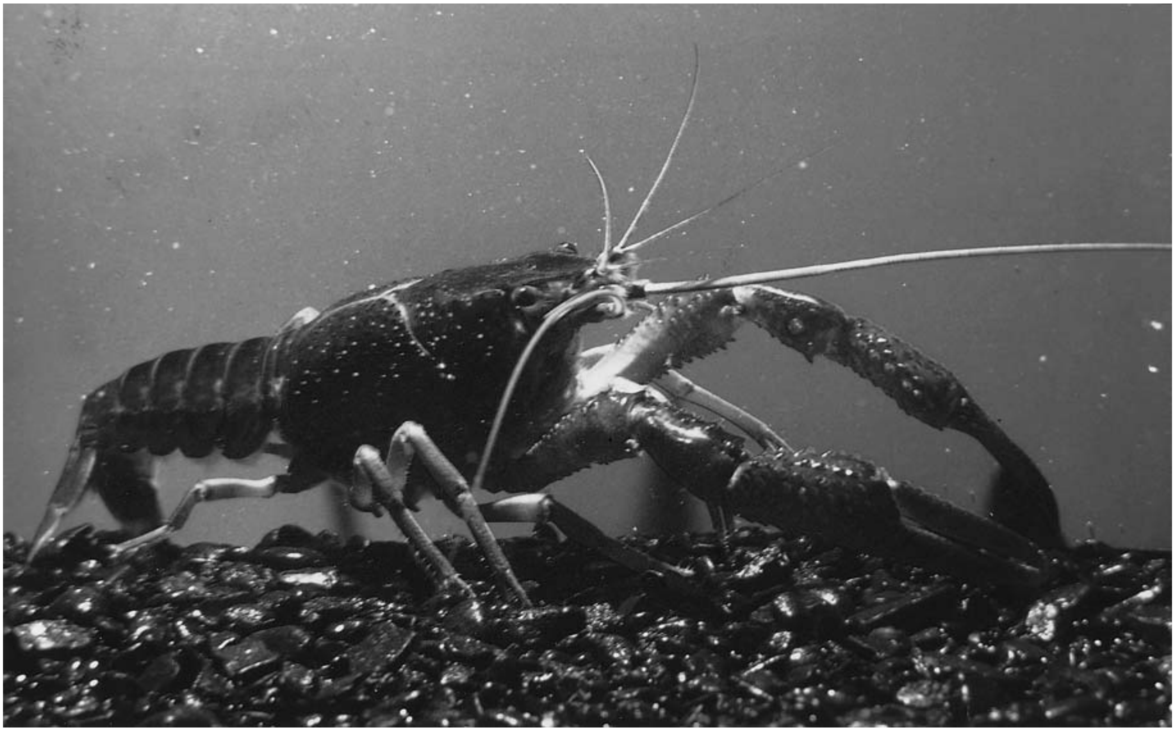

Fig. 11.1 The red swamp crawfish (*Procambarus clarkii*), which can be intercropped with *Macrobrachium rosenbergii*

11.2.2 Hatchery and nursery phases

In temperate climates the hatchery phase usually begins approximately 4 months before the planned stocking of juveniles into production ponds. The duration of a hatchery (or larval) cycle, from the hatching of eggs to the harvest of PL, usually occurs within a 28- to 30-day period (see Chapters 5 and 6). The restricted pond grow-out period in temperate regions presents some unique challenges for larval culture. There is only a 'window' of 3 or 4 weeks available for the production of PL. Thus, because of the need to stock grow-out ponds as early as possible, and an imposed 45- to 60-day nursery period, timing, planning and success during the hatchery phase is especially critical in temperate regions. There is no second opportunity to recover if problems which cannot be readily resolved occur, due to seasonal constraints. Special attention therefore needs to be focused on the quality of the broodstock and the cleanliness of the system.

Another special consideration for larval culture, dictated by the restricted growing season, is light. Larvae of *M. rosenbergii* actively feed by sight rather than by passive encounter and, therefore, must be cultured in indirect light with sufficient intensity to allow prey to be readily seen (see Chapter 6 for discussion of light requirements). During the hatchery season (late winter) the number of days with sufficient intensity are relatively few, requiring that natural light be supplemented with artificial light to achieve appropriate light conditions for culture. Larval tanks should be stocked with larvae hatched during a 1- to 4-day interval. Longer periods of larval collection would increase size variation within the culture tank, the incidence of cannibalism, and the length of the larval cycle. Chapters 5 and 6 provide detailed information concerning the management protocol in hatcheries.

In freshwater prawn farming the hatchery phase is generally followed by some form of nursery phase (see Chapter 8), a period when PL are commonly reared to juveniles in indoor tanks in freshwater. Due to the restricted outdoor growing season, a nursery phase is essential in temperate climates. The goal of this phase is to get a 'head-start' on grow-out while the animals are small and relatively tolerant of crowding. This helps to assure that marketable sizes are achieved, as well as decreasing post-stocking mortality (Sandifer & Smith 1985).

In addition, the nursery phase also provides for the implementation of another important management strategy, size grading, which is effective in reducing the size variation of harvested populations. A period of 45 to 60 days in the nursery at a stocking density of 5 to 6 PL/L is recommended (D'Abramo *et al.* 1995) to produce juveniles large enough that size grading (see section 11.2.5.1) can be effectively implemented (Daniels *et al.* 1995). Nursery tanks should be provided with artificial substrate at a rate such that PL are at approximately 400/m^2 of surface area. However, at this recommended stocking rate, the nursery phase should not exceed 60 days; after that the rate of cannibalism increases dramatically and significant losses can rapidly occur. Generally, a 65 to 75% survival may be expected at the end of the nursery phase.

11.2.3 Grow-out

In temperate climates prawns are usually stocked into grow-out ponds at the lower densities which are characteristic of semi-intensive culture. High stocking density is not advantageous with a growing season of approximately 4.5 to 5 months because growth is density-dependent. Hence, a marketable product cannot be achieved within the time-limited grow-out period. The density-dependent reduction in growth rates occurs in response to achieving a particular biomass per unit volume of water (D'Abramo *et al.* 2000). Therefore, this density-dependent factor will become operative earlier in high-density ponds where the population has a smaller mean weight. As a result, the mean harvest size is smaller at comparatively higher densities, given equivalent survival. D'Abramo *et al.* (1989) showed that average harvest weight decreased 23.2%, from 26.0 to 19.3 g, when stocking densities were increased from 39 536 to 79 072/ha.

Lower stocking densities are warranted by the short-duration, single-crop culture of prawns in temperate climates. This has an additional benefit, since the incidence of water quality problems arising from oxygen depletions is reduced when stocking densities are lower. Nevertheless, at high water temperatures, care needs to be exercised and management practices should call for either constant aeration or the initiation of emergency aeration procedures when dissolved oxygen concentrations are at, or are anticipated to fall below, 3 p.p.m.

Lower stocking densities also allow for the use of natural productivity for growth. At low stocking densities farmers can use the natural productivity of the pond to sustain maximum growth rates of juvenile prawns. However, at a biomass of approximately 200 to 250 kg/ha, natural pond productivity becomes insufficient to sustain maximum growth rates (Tidwell *et al.* 1997). At that point, feeding must be implemented. A commercially available sinking catfish feed, manufactured by pelleting or extrusion, works well, especially during the early stages of culture. This diet may serve to enhance natural productivity as much or more than serving as a direct source of nutrients. Nevertheless, some means to increase the overall energy flow is required. A fertilisation regime may either substitute or complement feeding (Tidwell *et al.* 1997). Careful attention must be directed towards the quantity, the frequency of application, and the time of day when fertilisers are applied, to avoid the possible depletion of oxygen that may occur as the material is decomposed. Grow-out feeds and feeding practices are presented in Chapter 13 and water quality and fertilisation in Chapter 14.

11.2.4 Effects of reduced temperatures on population structure

Macrobrachium rosenbergii is considered a tropical species requiring water temperatures of 26 to 31°C (Sandifer & Smith 1985) for good growth, with 29 to 31°C being considered optimal. However, Tidwell *et al.* (1994) reported rapid growth rates for prawns raised at a mean water temperature of 25°C. At this culture temperature, harvested prawns exhibited a population structure markedly different from those reported for populations in regions with higher mean water temperatures during the grow-out season. The primary differences were a reduced number of stunted males and a corresponding increase in the number of larger, faster-growing orange claw (OC) males.

These water temperature effects on pond populations were conclusively documented through a standardised study conducted using experimental production ponds located at different latitudes (Tidwell *et al.* 1996). This approach was designed to permit direct comparisons of production and population structure of prawns raised under different water temperature regimes. All variables such as stocking rate, stocking date, source of juveniles, diet, and feeding rates, were identical at both locations. At the more northerly (cooler) site fewer prawns reached sexual maturity and those that did were larger, indicating a delayed onset of maturation. This delay in attaining sexual maturity allowed prawns raised at lower temperatures to direct more energy to somatic growth and correspondingly less to maintenance and reproductive activities. Both total yield and growth rates were significantly greater at the more northerly (cooler) site (Fig. 11.2).

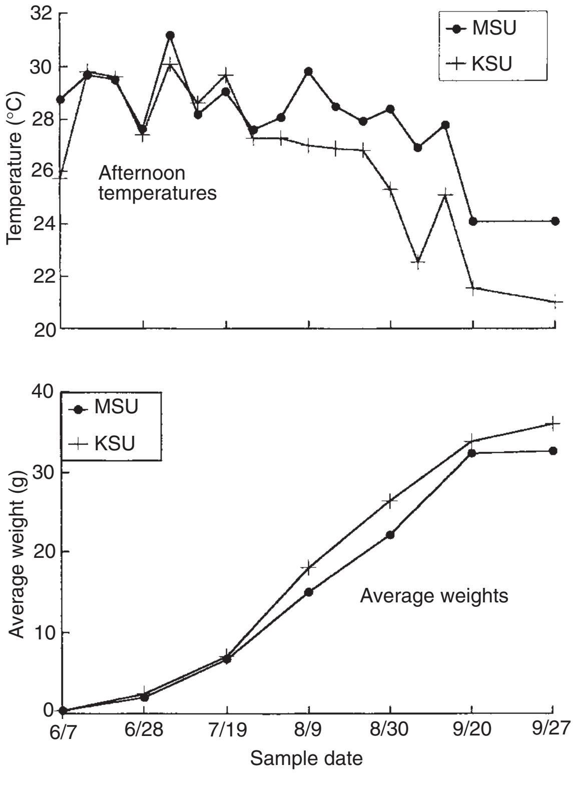

Fig. 11.2 Water temperatures and average weights of freshwater prawns raised under standardised conditions at southern (Mississippi State University [MSU]; latitude 33°12′) and northern (Kentucky State University [KSU]; latitude 38°12′) sites

11.2.5 Management of temperate grow-out systems to maximise growth

Development of management practices to maximise unit production in temperate regions is essential, due to the restricted length of the growing season. Total production can be increased by simply increasing stocking densities (Karplus *et al.* 1986); however, there is an inverse relationship between stocking density and mean prawn weight at harvest (D'Abramo *et al.* 1989). In fact, the proportion, and total production, of marketable-sized prawns may actually be lower at higher stocking densities (Smith *et al.* 1978).

Increasing average stocking size can also increase production. D'Abramo *et al.* (1989) demonstrated that an increase in stocking size from 0.17 to 0.75 g increased production by 16.8 to 39.6%, depending upon stocking density. At a stocking density of 39 536/ha the mean production at the end of the grow-out season increased by 29%. At higher stocking densities, the effect of larger stocking sizes was reduced because the density-dependent growth rate reductions become operative earlier in the pond grow-out phase. These results demonstrate that the nursery phase is essential in achieving the goal of producing prawns of a highly marketable size within the constraints of a short growing season.

11.2.5.1 Size grading

Size grading of nursed juveniles prior to pond stocking has been found to increase both mean harvest size and total pond production in temperate climates, thereby enhancing economic viability. Size grading is essentially a husbandry technique designed to separate fast-growing prawns from others in the nursery population. Faster-growing individuals are able to suppress the growth of other individuals in the population (the mechanism for growth suppression is discussed in Chapter 16). Removing or separating these fast-growing individuals improves the prospects that other individuals will achieve their growth potential. The smaller individuals, generally males, respond by increasing growth rates to compensate for their initial retarded growth. Essentially, size grading succeeds in disrupting the continuation of the socially induced, differential growth rates which contribute to increases in size variation in the population over time. D'Abramo *et al.* (1991) stocked ungraded and graded populations of juvenile prawns with a mean weight of 0.33 and 0.30 g, respectively, in earthen experimental ponds at a density of 29 652/ha. At the end of a 5-month grow-out season the mean harvest size and mean yield of the graded populations exceeded those of the ungraded populations by 37.3 and 45.6%, respectively. Mean food conversion ratios were also improved: 2.4 : 1 (graded) versus 3.2 : 1 (ungraded).

Size grading can be accomplished by using finfish bar graders. The desired separation is achieved through knowledge of the size distribution of the population, combined with selection of the appropriate bar width. A 50–50% (upper-lower) or 40–60% (upper-lower) size grade is advised because this approach allows the use of both post-graded populations for stocking. Having higher percentages of the upper class reduces the overall effect of size grading on production characteristics in ponds. Daniels & D'Abramo (1994) evaluated the production characteristics of graded and ungraded populations stocked and grown in earthen ponds for a period ranging from 125 to 138 days. The graded populations were numerically divided into 70% upper and 30% lower, and 30% upper and 70% lower groups, according to size. Average yield of the 30% upper (1106 kg/ha) and 70% upper (884 kg/ha) populations were significantly greater than that of the ungraded treatment (775 kg/ha) and corresponded to similar significant differences in mean harvest weight. These significant differences in production characteristics were a reflection of changes in the per cent distribution of different groups of individuals comprising the populations (morphotypes; see Chapter 16), a product of the size grading. Most importantly, based upon the size distributions of the harvested populations, the calculated gross revenues in graded populations were 6 to 73% greater than those realised for the ungraded populations.

Daniels *et al.* (1995) stocked the upper group of a size-graded population of juveniles into earthen experimental ponds at densities of 39 540, 59 300 and 79 100/ha. After a grow-out of 131 to 134 days, mean harvest weight was significantly higher for prawns stocked at the lower density relative to the two higher densities. There were no significant density-dependent differences relative to total yield, survival or feed conversion. The relationship of an increasing proportion of small males at harvest relative to increasing stocking density, a characteristic of ungraded stocked populations, was not found in their study. The significant differences in mean harvest weight were the result of an increase in the mean harvest weights of certain morphotypes rather than changes in the proportional distributions of the morphotypes. The higher mean harvest weight of populations harvested from the lower stocking density translated into higher revenue, based upon the proportions of tail count categories.

11.2.5.2 Artificial substrate

As noted earlier, in temperate regions it is important to increase total production rates without decreasing average individual weights. Cohen *et al.* (1983) reported that total production and average weight increased 14 and 13%, respectively, when artificial substrate was added to ponds in Israel. Tidwell *et al.* (1998) reported that production and average harvest size of prawns stocked at relatively low densities (59 280/ha), and grown under temperate conditions, increased 20 and 23%, respectively, when grow-out ponds contained added substrate. Ra'anan *et al.* (1984) reported that added substrate was more effective in intensively stocked production ponds. However, Tidwell *et al.* (1999b) found no significant interaction between the addition of substrate and increased stocking density, although substrate did increase total production by 18%, average harvest size by 13%, and marketable (>20 g) production by 25%. An unexpected benefit of added substrate was a 17% improvement in feed efficiency. The increased surface area provided by the substrate in the ponds most probably contributes to an increase in the supply of natural foods through enhanced periphyton production. Substrate provision on a commercial scale (Fig. 11.3) has resulted in production and mean harvest size exceeding 1800 kg/ha and 35 g, respectively (Tidwell *et al.* 1999a). In experiments conducted in 1999, it was found that substrate orientation (vertical *versus* horizontal) did not affect substrate efficacy (J. Tidwell, unpublished data 2000). When addition of substrate was combined with higher stocking rates (64 500/ha), and increased feeding rates, production exceeding 2500 kg/ha with average weights of >40 g was consistently achieved.

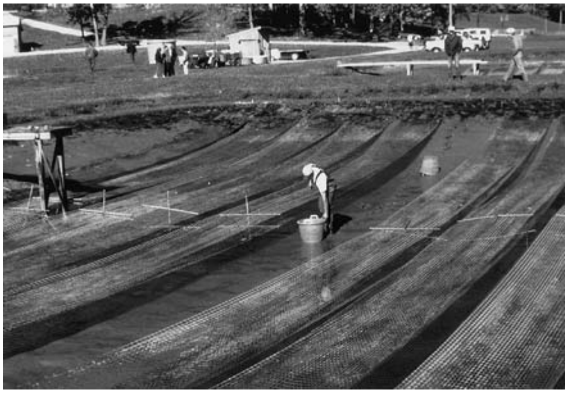

Fig. 11.3 Artificial substrate (PVC fencing) installed horizontally in a small (0.2 ha) production pond

Compared to finfish species which utilise the three-dimensional space which a pond environment provides, freshwater prawns are benthic animals and therefore limited by the two-dimensional surface area of the pond bottom. The concept of adding substrate is to utilise the three-dimensional volume better, by increasing the amount of two-dimensional surface available in the pond. This management approach may make prawn production feasible in smaller, deeper ponds which were previously considered unsuitable. This is advantageous in hilly inland regions where suitable sites for large shallow ponds are very limited.

Added substrate can be permanently installed in ponds equipped with catch-basins at the drain end. As the water is drained, prawns will leave the substrate and follow the flow of water to the catch basin. This approach eliminates the labour required for removal of substrate at harvest. In addition, the materials needed and labour involved in installing substrate can be amortised over several production cycles.

11.2.6 Harvesting

In temperate regions the harvesting of the total pond population of prawns must occur before water temperatures drop below 17°C. However, some animals may attain marketable sizes 4 to 6 weeks before final harvest. In tropical regions, selective harvests have been implemented to improve total production by removing aggressive morphotypes, thereby disturbing an established behavioural hierarchy and allowing less dominant animals to respond with higher growth rates. In most temperate regions the time between the initiation of selective harvest and the temperature-imposed final harvest does not appear to favour this management practice. However, a partial or selective harvest may be beneficial if it spreads the marketing season over a longer period. General harvesting techniques for freshwater prawns are discussed in Chapter 10.

The use of a seine is relatively inefficient for harvesting in temperate zone prawn culture. Seining without draining may leave as much as 25% of the crop in the pond. Efficient total harvesting of batch production may be achieved through the addition of a catch basin within a drainable pond. When the water is drained, prawns are concentrated in the basin. Sufficient aeration must be provided to this basin to avoid any oxygen deficiencies. If a pond is properly constructed, then very few prawns will become trapped on the pond bottom during draining. In ponds with added substrate, the substrate can be left in place because prawns will move out of the substrate to the catch basin as the water level drops.

Handling of prawns during and after harvest is partially determined by the type of market being addressed. In temperate areas where fresh, and especially live, markets are important, harvesting methods that reduce the incidence of handling stress as much as possible must be employed to ensure long-term post-harvest survival. These methods include aeration of the harvest basin, purging in clean, aerated, holding tanks, and harvesting and holding at lower water temperatures (20–22°C).

11.3 Marketing strategies

The general marketing principles applied to freshwater prawn farming are discussed in Chapter 19. Successful commercial culture of freshwater prawns in temperate regions would allow prawns to be raised in close proximity to inland urban markets where product forms such as head-on, live, or even fresh product are usually unavailable (Fig. 11.4). In these regions freshwater prawns may be considered in a pricing structure that is separate from frozen marine shrimp. In Kentucky, USA, farm-gate prices for live freshwater prawns of mixed sizes achieve US$ 13.2–22.0/kg. Higher selling prices should compensate for the lower annual yields imposed by seasonal production in temperate regions.

The higher selling prices that prawns need to command, when compared to frozen shrimp tails, might also be justified relative to size and quality. Current financial pressures originating from the frequent incidence of disease (Chamberlain 1994) are causing marine shrimp to be harvested at comparatively small sizes, resulting in an overabundance of small to medium sizes but an insufficient supply of larger sizes. In fact, many of the larger size and higher priced deheaded 'shrimp' currently being sold in markets in the USA are actually deheaded freshwater prawns. Prawn producers who have established a goal of producing large average sizes are readily locating markets for individuals that weigh more than 35 g.

Currently, there is a desire on the part of consumers to know something about the conditions under which food is raised. Consumer acceptance may be enhanced by knowledge of the sustainability or responsibility of their production methodology (see Chapter 23). This provides an opportunity for producers in temperate regions who are close to potential markets to demonstrate their rearing techniques to the public. The development of

Fig. 11.4 A family-owned supermarket in Toronto, Canada, that offers live prawns and fish

Table 11.1 Effect of different management practices on per cent increase of mean individual harvest weight and total production of freshwater prawns grown in experimental earthen ponds in temperate regions.

Management practice	Mean initial stocking weight (g)	Initial stocking density (no./ha)	Mean harvest weight (% increase)	Mean yield (% increase)	Study
Stocking larger juveniles	0.76 *versus* 0.17	39 530	32.7	29.2	D'Abramo *et al*. (1989)
	0.76 *versus* 0.17	59 304	13.3	1.9	D'Abramo *et al*. (1989)
	0.76 *versus* 0.17	79 072	16.8	8.0	D'Abramo *et al*. (1989)
Grading of juveniles before stocking	0.30 and 0.14 (graded) *versus* 0.33 (ungraded)	29 652	37.3 and 4.3	45.6 and 11.0	D'Abramo *et al*. (1991)
Grading of juveniles before stocking	0.15 and 0.40 (graded) *versus* 0.16 (ungraded)	39 530	5.8 and 45.7 (17.7[a])	1.9 and 42.7[b] (14.3[a])	Daniels & D'Abramo (1994)
	0.10 and 0.21 (graded) *versus* 0.16 (ungraded)	39 530	12.8 and 16.5 (15.2[a])	11.4 and 14.1[b] (13.3[a])	Daniels & D'Abramo (1994)
Higher latitudes (38°12′ versus 33°28′)	0.26	39 530	3.7	15.6	Tidwell *et al*. (1996)
Addition of horizontal substrate[c]	0.33	59 280	23.0	19.6	Tidwell *et al*. (1998)
Addition of horizontal substrate[c]	0.24	60 000	25.1	7.0	Tidwell *et al*. (1999b)
	0.24	120 000	nil	27.3	Tidwell *et al*. (1999b)
Addition of horizontal substrate	0.31	74 100	2.0[d]	13.6	Tidwell *et al*. (2000)
	0.31	74 100	8.6[e]	24.5	Tidwell *et al*. (2000)

[a] Weighted average of both graded groups.
[b] Based on % survival as a co-variate.
[c] 80% of pond bottom, including open area of the mesh.
[d] 40% of pond bottom, not including open area of mesh.
[e] 80% of pond bottom, not including open area of mesh.

regional 'festivals', based on the harvest and consumption of fresh product, could further satisfy this consumer demand for information.

11.4 Summary of the potential

The data discussed in this chapter indicate that more economically viable culture of *M. rosenbergii* can be extended to cooler latitudes than previously considered possible. Critical to the success of farming in temperate climates is the implementation of three management practices: stocking of advanced juveniles, size grading of juveniles, and substrate provision in grow-out ponds (Table 11.1). These management practices are designed to minimise the major limiting factors of seasonal culture, the limited duration of the growing season, and the growth impacting social interactions which are a biological characteristic of this species. The economic benefits derived from each of these management procedures will far outweigh the increase in operational costs. These management techniques have not yet been combined into 'best management practices' for collective analysis. Stocking advanced juveniles, between 0.3 and 0.5 g, has already resulted in production rates of 1000 kg/ha with a mean harvest weight of ⩾30 g. The addition of artificial substrate has resulted in higher production rates, 1800 kg/ha being achieved in <140 days, while maintaining mean harvest weights of >35 g. Size grading of juveniles prior to stocking should increase mean annual production rates even further. When these management practices are combined, we believe that production rates approaching or exceeding 2000 kg/ha, with a mean harvest size of >30 g, can be regularly achieved in less than 150 grow-out days. These production levels, combined with the unique marketing opportunities associated with inland production, are a strong foundation for economically feasible production of freshwater prawns in temperate regions of the world.

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12

Grow-out Systems – Polyculture and Integrated Culture

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Polyculture, the art of growing two or more compatible aquatic species together in a single pond, has the objective of maximising production using organisms with different feeding habits or spatial distribution. It is distinct from integrated systems, which combine aquaculture with the farming of terrestrial animals and plants.

Hepher & Pruginin (1981) described the most important aspect of polyculture as the ability to increase productivity through a more efficient utilisation of the natural food available. However, there is a consensus that the inclusion of a higher value species – even though this may not necessarily result in an increase in productivity – can yield a significantly higher income for the farmer. The priorities of a polyculture system are: a more rational use of the pond with species having different feeding habits; the additional income from certain low-density species; and, most of all, the increased production of the species most in demand from the market – generally the freshwater prawn itself.

Knowledge of the feeding habits of the species that will be cultured with the freshwater prawns is essential. Ponds may have a large number of food niches, but not all may be present in abundance at the same time. For example, channel catfish grow-out ponds may lack filamentous algae and higher plants; milkfish ponds may have an abundance of filamentous algae and zooplankton but be deficient in phytoplankton. Also, some fish feed on the faeces of other fish. Avault (1996) noted that tilapia feed on the faeces of common carp, which in turn feed on the faeces of silver carp.

The polyculture of fish is common in tropical aquaculture, but it is less usual for freshwater prawns to be included, despite the considerable amount of research on the subject. Brown *et al.* (1991) commented that polyculture considerably complicates the grow-out management of prawns. New (1990, 1995) noted that the results of polyculture studies of *Macrobrachium rosenbergii* with fish and other crustaceans present a rather confused picture. These reviews show that while some workers in the USA reported that the presence of tilapia did not depress the growth of prawns (and that the presence of prawns and crawfish did not affect the growth of tilapia), others reported that tilapia reproduction had an adverse effect on prawn yield. In the latter case, however, prawn–tilapia polyculture still provided a potentially greater net return than prawn monoculture. In Israel, some workers found that prawn yield was influenced only by prawn stocking rate and not by the species of fish used (common carp, tilapia and various Chinese carps) or by different fish stocking rates or different feeding and manuring regimes. However, the growth of carp and tilapia polycultured with prawns appeared to be strongly affected by the number of tilapia stocked and the feeding/manuring strategy.

This chapter reviews the interactions between freshwater prawns (generally *M. rosenbergii*) and other aquatic species with which they are polycultured, the management of prawn polyculture systems, and prawn–crop integration. Further information about these topics related to commercial aquaculture around the world is provided in Chapter 17, while information on the culture of other *Macrobrachium* spp., in both monoculture and polyculture, is provided in Chapter 21.

12.1 Fish and prawn interactions

Freshwater prawns have been polycultured with a variety of compatible species of fish and crustaceans and their interactions in terms of food niches and habitats vary from situation to situation. The most commonly used species are: tilapias; common, silver, grass and bighead carps; and catfish. The presence of all these fish species results in improvements in water quality. Similarly, most occupy a food niche which is complementary to freshwater prawns. The exception is bighead carp, which is due to their zooplanktonic habit.

According to Hepher & Pruginin (1981) tilapia and prawns feed on benthic detritus in a multispecies polyculture system, decreasing the amount of material to be decomposed by bacteria and thus reducing the biochemical oxygen demand. In addition, tilapia and freshwater prawns consume the faeces of grass and common carp. Common carp feed on partially digested algae from silver carp faeces. Prawns are not able to 'filter' free algae directly from water. On the other hand, the increase in diversity and density of animals in polyculture reduces the populations of unwanted species. The same authors made special reference to the filtering capacity of silver carp, which feed on microscopic (30–40 µm) phytoplankton, emphasising that this is an appropriate species for polyculture with other carps and *M. rosenbergii*. The authors stated that one 250 g fish can filter up to 32 L of water/day. From 500 to 600 g, they can grow about 10 g/day in polyculture. Silver carp prevent sudden algal blooms. Despite all these advantages, marketing silver carp, a fish with many bones, is a problem and this species only commands a low price. Parameswaran *et al*. (1992) showed that the polyculture of freshwater prawns with the Indian carp rohu (*Labeo rohita*), together with silver (*Hypophthalmichthys molitrix*) and grass (*Ctenopharyngodon idella*) carps enhanced total production. Additionally, the carps prevented the growth of phytoplankton, zooplankton, macrovegetation and filamentous algae from getting out of control.

An important factor influencing the compatibility of prawn/fish interactions is the size of animals stocked. If prawns are stocked too small they are vulnerable to fish predation. Conversely, large prawns may predate on fish fry, so careful management practices are essential. Cannibalism amongst prawns does not seem to be exacerbated by the presence of other fish or crustaceans. Martino & Wilson (1986), comparing the feeding behaviour and growth of prawns with two very similar species in terms of feeding habits, namely the Mossambica tilapia (*Oreochromis mossambicus*) and the American crawfish (*Procambarus clarkii*), concluded that most observed interactions were intraspecific, and that the cannibalism which was detected among crustaceans was not influenced by the presence of tilapia.

The qualitative and quantitative contributions of supplied feeds and naturally occurring foods to the growth of most fish and prawns in polyculture are not well known. *Macrobrachium rosenbergii* has been classified as a benthophagic omnivore, based on analyses of stomach contents (Cohen & Ra'anan 1983). D'Abramo *et al*. (1986) noted that prawns stocked as postlarvae (PL) and juveniles could be successfully cultured with channel catfish, either stocked as fry, fingerlings or food-size fish. However, their ecological relationship was not well known. 'Unfed' polycultured prawns in catfish ponds subsist principally on faeces, or formulated feed not consumed by the fish, and to a lesser extent on aquatic biota. Lilyestrom *et al.* (1987) also showed that, when polycultured with channel catfish (*Ictalurus punctatus*) fed formulated rations, freshwater prawns made less use of the artificial feed than the catfish. Examination showed that the stomach contents of catfish were dominated by formulated rations, while those of freshwater prawns contained macrophyte fragments as well as the catfish feed and faeces. It was concluded that formulated feeds contributed 68 to 99% of catfish growth, and 'natural' pond biota, principally insects, the remainder. These authors concluded that the phytoplanktonic and the detrital food webs were both important, albeit for different developmental stages. In this study, seston and macrophytes contributed 18 to 75% of prawn growth, and formulated feeds the remainder. The prawns fed on seston at small sizes (<7 g) but consumed more aquatic macrophytes and formulated catfish diet at larger sizes (>7 g). This may also happen with other fish species polycultured with *M. rosenbergii.* Despite the fact that prawns did not compete well with catfish for pelleted feed, Lilyestrom *et al*. (1987) reported that polyculture appeared to have no adverse effect on the survival, growth or yield of either species.

A new area of study which affects polyculture systems, namely the chemical communication among aquatic species and its effect on behaviour, may also prove to be of interest when crustaceans are included in the system. In crustaceans, chemical communication occurs in a variety of forms. One example is that of the 'disturbance pheromones' reported in crawfish, whereby non-injurious stress or disturbance to crawfish results in the release of chemicals which other crawfish can detect. Recipient crawfish appear to go on low-level alert when the chemicals are detected (Hazlett 1990). This may also occur with *M. rosenbergii*. Most of the pheromones that have been studied are sexual in nature, such as the humoral pheromone 17-alpha, 20-beta-dihydroxy-4-pregnen-3-one (17,20 β-P), gonadotropin hormone (GTH) and prostaglandins (PGFs).

Almost all studies on the chemical communication of aquatic species concern finfish, particularly carps, tilapia and goldfish, and 17,20 β-P. Zheng *et al*. (1995) applied sex pheromones to enhance fertility in male cyprinids. In common carp, the stimulatory pheromonal effect of 17,20 β-P on milt volume did not occur if fish were exposed and stripped at frequent intervals (3–7 days). In goldfish, 17,20 β-P exposure increases fertilisation rate at the onset of spawning. Bjerselius *et al*. (1995) evaluated the endocrine, gonadal and behavioural responses of wild male Crucian carp to the same humoral pheromone and concluded that the male carp uses the 17,20 β-P signal from the females to prepare for the coming spawning. The results of a study conducted by Stacey *et al*. (1994) suggested that 17,20 β-P has a pheromonal role in milt production in common carp similar to that demonstrated in goldfish. These authors concluded that waterborne 17,20 β-P might be a practical non-invasive technique for enhancing milt production in cultured common carp.

This topic has been briefly introduced into this chapter because fish sexual pheromones may also have a role to play in prawn polyculture if the fish used attain sexual maturation. Tilapias will certainly do so, since their life span under culture is similar to *Macrobrachium*. It is quite common in sub-tropical areas (e.g. of Brazil) to include tilapias and prawns in the second year of carp production, in order to fully utilise the final summer season. Under these conditions, carps may also produce sexual pheromones. There is a need for further studies on this subject, and on the possible effects of fish pheromones on prawn growth and *vice versa*.

12.2 Management of prawn polyculture systems

In order to design a polyculture system it is necessary to consider species compatibility, interactions with the environment, stocking size, and, essentially, the targeted market and its economics. The production costs of prawn culture may be lowered by the correct choice of fish species and their stocking rates. Fish that 'filter' the pond water are quite efficient in this respect. In a recent review on the polyculture of the freshwater prawn *M. rosenbergii* with other aquatic species, Zimmermann & Rodrigues (1998) found more than 50 papers on the subject. Among them, 37 references involved 'filtering' fishes, i.e. phytoplanktophagous species such as silver carp and tilapias. Other papers referred to the polyculture of *M. rosenbergii* with a wide variety of other species: other freshwater prawns (Martinez-Silva *et al*. 1985; Rajyalakshmi & Maheswardu 1986; Durairaj & Umamaherswari 1991), freshwater crawfish (D'Abramo & Daniels 1992), mullets (Cohen 1989; Hulata *et al*. 1990), catfish (Cohen 1985; Avault 1986; D'Abramo *et al.* 1986; Heinen *et al*. 1987; Lamon 1988), marine shrimp (in rotation) (Srinisavan *et al*. 1997), and aquatic plants (Das *et al.* 1991; Roy *et al*. 1991).

12.2.1 Water quality

Several characteristics of water quality are influenced by polyculture. The effect is almost always positive, including a decreased need to exchange water in ponds. According to Hepher & Pruginin (1981), the beneficial effects of polyculture are due to dissolved oxygen (DO_2) stability, reduction of predators and coprophagy. For example, silver carp and tilapias consume excess algae, lowering nocturnal respiration without reducing oxygen levels (Barthelmes *apud* Hepher & Pruginin 1981). Rouse *et al*. (1987) and Alston (1989) also noted the advantages of introducing tilapias in prawn ponds, mainly on the physical and chemical aspects of water quality, but Fitzgerald (1988) showed that these advantages might vary from year to year.

In experiments in commercial ponds without controls, Tunsutapanich (1980) described the stocking of 5/m^2 of *M. rosenbergii* with carps at 30 to 125/ha comprising grass carp, silver carp, and bighead carp (*Aristichthys nobilis*), together with 6000 to 12 000/ha of mosquito fish (*Gambusia* sp.). After 7.5 months, prawns yielded 1340 kg/ha with an average weight of 40 g; 625 kg/ha of carps of 2 to 3.5 kg each were also obtained. This author concluded that since the level of prawn production achieved was no different to that normally obtained in monoculture, this form of polyculture was valuable because it resulted in good pond water quality, fewer algal problems, and a higher decomposition rate of organic matter from pond sediment. In addition, it provided an extra income from carps and bait-fish (mosquito fish). This form of polyculture decreased the need to exchange water in ponds. These preliminary studies were also described by Tunsutapanich *et al.* (1982) who, while noting that statistical analysis was impossible because of the lack of controls and replication, commented that they provided guidelines for extension work.

Muñoz Cordova & Garduno Lugo (1993) evaluated the polyculture of *M. rosenbergii* at 1.3/m^2 with tilapia (*Oreochromis hornorum*) stocked at 13 000/ha in 100 m^2 earthen ponds. At stocking, prawns averaged 0.58 g and tilapia 0.16 g. Cow manure and simple superphosphate were applied twice per week. Supplementary feeding at 3% of biomass daily produced the equivalent of 406 kg/ha/yr of prawns with a mean weight of 26.5 g, together with 1957 kg/ha/yr of tilapia (average 98.3 g) in one pond. However, a bloom of blue-green algae in the second pond caused low DO_2 and, possibly, the release of algal toxins; production in this pond was only 42 kg/ha/yr (average 64 g) and 1233 kg/ha/yr (70 g) for prawns and tilapia, respectively. These authors noted that although this type of polyculture has interesting potential, careful management is clearly necessary.

12.2.2 Feed

Various feeding strategies are used in polyculture systems, but there is a tendency to use simple diets such as low-cost farm-made formulated rations, simple mixtures of feed ingredients, and organic matter (New *et al.* 1993). Since fish are faster than prawns in accessing any feed that is presented, and prawns are able to utilise fish faeces, most feeding regimes employed in prawn polyculture are directed at the fish rather than at the prawns. For instance, a mixture of rice bran and mustard oilcake (1 : 1) was supplied by Hoq *et al.* (1996) when *M. rosenbergii* was polycultured with five species of Indian and Chinese carps. When pelleted feed is provided, it may be supplemented with another ingredient. For example, John *et al.* (1995) fed a 25% pelleted feed at 3 to 5% of body weight daily, together with the groundnut oil cake conventionally utilised as a fish feed ingredient in the Indian sub-continent. In their study, these authors examined the effect of rearing *M. rosenbergii* and *M. malcolmsonii* in monoculture, bi-species culture, or composite culture with common and silver carps in earthen ponds of 500 m^2 and 1000 m^2 for a period of 6 months with an uniform prawn stocking density of 2/m^2. The prawns performed better in composite culture ponds than in the other two types of trials.

12.2.3 Stocking strategies and results

Stocking strategies vary from region to region and from farm to farm, but the literature which deals with this subject is more abundant in Israel, where the methodology seems to be more refined than elsewhere, and the compatibility between studies is better (Karplus *et al.* 1987, 1990; Sarig 1992). The polyculture of prawns with several finfish species, including carnivores, was commonplace there and the success of the stocking strategy was found to depend on the use of compatible stocking sizes of each species (Hulata *et al.* 1988). Roberts & Kuris (1990) noted that prawns may be predators, depending on the size of the fish. These authors recommended the introduction of carps and tilapias with prawn juveniles weighing 0.25 to 0.50 g at a density of 2/m^2. This stocking density was also used by Karplus *et al.* (1987), who obtained excellent results rearing juveniles of three sizes in 400 m^2 ponds in polyculture with tilapias (*Oreochromis* sp.), common carp (*Cyprinus carpio*), silver carp, and grass carp.

Mires (1987) successfully stocked *M. rosenbergii* juveniles at 5 to 7.5/m^2 in polyculture with Nile tilapia (*Oreochromis niloticus*) fingerlings stocked at 6000 to 7000/ha. The yield was 1045 kg/ha of prawns and 2700 kg/ha of tilapias after 180 days, with a net income of US$ 5309/ha and US$ 4095/ha, respectively. The higher prawn stocking density used made periodic selective harvests necessary; these started from day 120 onwards. Hulata *et al.* (1990) described a study in which the effects of the size and age of *M. rosenbergii* reared simultaneously with several species of carp and tilapia were examined. Prawns were stocked at $2/m^2$, while fish were stocked at 2500/ha (common carp), 9000/ha (tilapia hybrids – various combinations of *O. niloticus* × *O. aureus* or *O. niloticus* × *O. urolepsis hornorum*), 550/ha (*Omossambicus* × *O. aureus*), 350/ha (red tilapia), 500/ha (silver carp) and 250/ha (grass carp). Prawns ranged from 0.25 to 0.53 g at stocking and carps and tilapias from 79 to 389 g. Over 86% survival of all species was achieved in a 5-month trial, except red tilapia (51%). Silver carp grew from 95 g at stocking to 1208 g on average at harvest, while prawns were harvested at 38 to 40 g.

Stocking strategies tested by Ahmed *et al.* (1996) compared two 0.1 ha ponds, stocked with *M. rosenbergii* juveniles at $0.6/m^2$ in addition to silver carp, catla (*Catla catla*), rohu, and mrigal (*Cirrhinus mrigala*) at 5000/ha in the carp ratio 3.5 : 1.5 : 3.0 : 2.0, with two other similar-sized ponds stocked only with fish in the same ratio. The ponds were fertilised with triple superphosphate and urea every fortnight at 25 kg/ha; feeding rates, based on an unspecified 32% crude protein diet, were based on prawn and carp biomass. No difference in the physico-chemical and biological characteristics of pond water in either treatment was observed. Total production of 2980 and 2347 kg/ha were obtained for prawn–carp and carp cultures, respectively. Prawns attained a mean body weight of 100 g with a daily gain of 0.42 g, total production being ~600 kg/ha. Fish growth was not influenced by either of the polyculture systems examined.

The effect of six monoculture and polyculture (with tilapia and carp) systems differing in stocking rate and stocking size on prawn claw-off yield were examined in a study performed by Sadek & Moreau (1996). The interaction between fry size, density, and sex, and the cost–benefit aspects of the different strategies, were also studied. Experiments were carried out in 18 earthen ponds, 0.125 ha each, with a mean depth of 1 m. Prawns were stocked at 2 or $5/m^2$ in monoculture in triplicate; six ponds received prawn PL of 0.3 g, while the other six received juveniles weighing 2 g. In polyculture, 0.3 g PL were stocked at a density of $2/m^2$. *Oreochromis niloticus* fry (<1 g) were stocked at 10 000/ha and *Cyprinus carpio* (15 g) at 2500/ha in three ponds; three other ponds were stocked with tilapia at 20 000/ha and carp at 5000/ha (see also Section 12.2.5).

Rodrigues (1988a,b, 1995) described several polyculture systems which included *M. rosenbergii* that had been found suitable for Southern Brazilian subtropical conditions. This author stressed the value of introducing prawns into fishponds and noted the need for synchronicity in the production scheme to ensure a single harvest. He also characterised the stocking management, which is different to traditional polyculture systems involving fish only. In these studies, freshwater prawns were stocked at 2 PL/m^2 or 1.5 $juveniles/m^2$ in combination with grass, silver, bighead and common carps, with or without all-male Nile tilapia, in various stocking ratios and strategies (see also Section 12.2.5).

Studies on the effect of stocking strategies on the interactions of tilapia and prawns were conducted by McGinty and Alston (1993). In an initial trial, two 0.7 ha ponds were stocked monthly with 3300 male tilapia (*Oreochromis* sp.) fingerlings (4714/ha) and bimonthly with 15 000 prawns ($2.14\,PL/m^2$). A dorsal spine was clipped to differentiate each monthly cohort of tilapia stocked. Tilapia and prawns received a 32% protein diet at a rate based on estimated fish biomass. Ponds were seined at monthly intervals to determine the growth rates of prawns and tilapia and to remove marketable animals. A maximum feed input of 55 kg/ha/day was established to obtain rapid growth of the fish. This feeding rate proved to be desirable for the tilapia; however, it caused low DO_2 at dawn which proved fatal to the prawns. Beginning 19 weeks after the first stocking, an average of 730 kg/ha of tilapia averaging 400 g each could be harvested monthly. There were no differences in the growth curves of different monthly cohorts of tilapia, revealing little or no negative inter-group interaction. In a second trial, two 0.7 ha ponds were stocked initially with 5000 male tilapia fingerlings (7243/ha) and 40 000 juvenile prawns ($5.7/m^2$). Beginning at month 3.5 and monthly thereafter, the ponds were seined and marketable animals harvested. For every tilapia harvested, 1.08 tilapia were restocked, and for every prawn harvested, 1.33 prawns were re-stocked. To reduce the incidence of low DO_2 and to increase prawn survival, a daily input of 40 kg of feed was set as the maximum. After eight monthly harvests, the average yield per harvest equalled 436 kg/ha of tilapia and 107 kg/ha of prawns. This second system offered good potential for small farms that need to supply markets on a regular basis. Annual yields appeared to be similar to those from batch harvest systems. It was easier to meet the demands for replacement animals since all the seed stock are not required at one time, as they would be for batch harvest systems.

Two current polyculture systems in China, in which prawns are grown with silver and bighead carps, are described in Chapter 17. Where the emphasis is on prawn production, about 1.2 to 1.8 t/ha/crop of prawns and 0.75 to 1.5 t of fish are achieved. Where finfish are the primary crop, prawns are stocked at a lower rate and the yield is typically 0.3 to 0.9 t/ha/crop of prawns and 5.25 to 7.5 t of fish. Polyculture systems may not always provide greater yields of freshwater prawns than monoculture. For example, Siddiqui *et al.* (1996) cultured *M. rosenbergii* with Nile tilapia and common carp, obtaining a yield of prawns in polyculture (711 kg/ha) which was significantly less than that from monoculture (1152 kg/ha). The mean prawn harvest weight, 21.3 g after 196 days of polyculture, was also significantly less than that from monoculture (30.2 g). However, the total yield from polyculture, including tilapias (2544 kg/ha) and common carp (2999 kg/ha), was almost five times as great as from prawn monoculture. Survival and food conversion rate of *M. rosenbergii* did not differ significantly between monoculture and polyculture.

Some believe that the survival and growth of freshwater prawns depend more on factors such as water quality and feed than on the particular species with which they are polycultured, but this is not always so. Reddy *et al.* (1988) showed that the choice of finfish species included in prawn polyculture had a significant effect. These authors stocked *M. malcolmsonii* with the Indian major carps *Catla catla* and *Labeo rohita* and their hybrid (*L. rohita* male × *C. catla* female), and the exotic carps *Ctenopharyngodon idella* and *Cyprinus carpio* var. *communis* in different combinations in earthen ponds. The continuous prawn culture system, with two stockings and multiple harvests in a 390-day grow-out period was followed. In the trials with the Indian major carps and their hybrid, survival of *M. malcolmsonii* ranged from 51.4 to 68.8% while 28.7 to 49.8% attained market size. Market-sized males were recorded at 20 to 98 g and females at 20 to 50 g during multiple culling. In combination with grass carp, however, survival of prawns was only 6.8% and only 5.2% reached market size. Similarly, experiments with common carp resulted in 14% prawn survival, while only 2.1% reached market size. Male prawns cultured with grass carp and common carp attained a harvest size of only 20 to 42 g, while females achieved 20 to 26 g.

The results of Reddy *et al.* (1988) and Siddiqui *et al.* (1996) indicate that the performance of prawns in polyculture may be inferior compared with monoculture, and depend on the fish species with which they are reared. However, where the production of finfish is the major activity, there are significant economic benefits to be achieved by including freshwater prawns in polyculture systems (see section 12.2.6). In addition, experience in China demonstrates that the respective levels of prawn and fish production can be manipulated by varying management. Either prawn or finfish yield can be maximised, according to demand.

Contrary to common belief, polyculture of prawns with carnivorous fish may be suitable when there are unwanted hatches of predator fish or mixed populations of tilapias. In such polyculture systems, it is normally recommended that carnivorous fry or fingerlings, which are smaller that the non-carnivorous species, should be stocked so that the survival of the non-carnivorous species will not be affected. Mendes *et al.* (1998a,b) performed several polyculture trials of *Macrobrachium* spp. with ornamental carnivorous fish and considered that the survival and growth of both fish and prawns were normal.

An important criterion, when determining species compatibility in polyculture systems, is the method and timing of the harvest of each species. Harvesting a single species from a polyculture system is difficult. Hepher & Pruginin (1981) and Rodrigues (1988a,b, 1995) noted that the fish should be stocked in a way that will ensure that they will attain their commercial size at the same time, since selective harvests always cause losses of

Table 12.1 Typical stocking densities for freshwater prawns in polyculture with carps and tilapias.[a]

Species	Average stocking rate No./ha (range)	Average yield kg/ha/yr (range)
Freshwater prawns		
Postlarvae	40 000 (4000–100 000)	1050 (150–3700)
Juveniles	20 000 (2000–70 000)	1350 (670–4200)
Tilapias		
Oreochromis niloticus	11 000 (3000–20 000)	5000 (910–9000)
O. aureus	2 500 (2000–7000)	1500 (800–2000)
O. hornorum	3 800 (2500–8000)	2100 (950–4200)
Hybrids	6 000 (1000–16 000)	4800 (700–7000)
Carps		
Ctenopharyngodon idella	80 (60–740)	2000 (300–3700)
Aristichthys nobilis	550 (200–1000)	1200 (410–2000)
Hypophthalmichthys molitrix	2 000 (600–5000)	2600 (720–6000)
Cyprinus carpio	4 000 (800–8000)	4000 (950–8000)

[a] These figures show approximate averages and ranges of stocking rate and yield, based on a survey of the literature by Zimmermann & Rodrigues (1998). When several species of fish are used in the polyculture system, the stocking rate tends to be the lower rate; conversely, when only one fish species is stocked with prawns, the stocking rate tends to be at the higher rate.

the remaining fish and prawns. The rotation of *M. rosenbergii* with other seasonal crops has also proved advantageous.

Typical stocking densities and yields from freshwater prawn polyculture performed in semi-intensive systems are given in Table 12.1. In the papers summarised there, the culture cycle ranged from 3 to 6 months and the water temperature was 26 ± 4°C.

12.2.4 Rotational strategies

Granados *et al*. (1991) and Avault & Granados (1995) reported on the results of the crop rotation of *M. rosenbergii* with another crustacean, the red swamp crawfish (*Procambarus clarkii*). This study set out to determine if these two crustaceans were compatible and whether total (unit area) production could be increased. Brood crawfish were stocked into ponds at rates of 0, 60, 120, or 180 kg/ha on 18 April. Following this, rice was planted in the ponds as forage. Post-larval prawns were stocked on 3 July in all ponds at 17 500/ha. Half of the ponds were fed and half were not. Ponds were drained from 7 to 11 October, yielding from 157 to 248 kg/ha of prawns with a survival of 69 to 88% and an average size of from 11 to 17 g. There was no significant difference ($P > 0.25$) between fed and non-fed treatments. The ponds were then reflooded and crawfish were harvested from 15 January to 15 May. The average yield of crawfish ranged from 746 to 1266 kg/ha. Crawfish yields did not differ with stocking rate ($P > 0.25$). Overall, prawns and crawfish were thus compatible in rotation. Prawns, though small, were of a good size for soft-shell production during months when crawfish are not available for this purpose. Avault (1990), noting that prawns are relatively uniform in size up to 17 g, which is an ideal size for the soft-shell trade, mentioned some preliminary experiments on the production of *M. rosenbergii* for this market, which were later also reported by Caffey *et al.* (1993). The use of soft-shell crawfish shedding facilities for the summer and autumn production of soft-shell prawns seemed technically feasible.

Similarly, D'Abramo & Daniels (1992) found that combining the same two seasonal crops, namely the red swamp crawfish and *M. rosenbergii*, increased the probability of financial success. Juvenile prawns stocked at 39 530/ha (3.953/m^2) in mid-May of year 2, in ponds stocked the previous year with broodstock crawfish and harvested in October, resulted in a production of 1444 kg/ha crawfish and 855 kg/ha prawns in year 2. Both crawfish and prawns were fed artificial diets and the latter achieved a feed conversion ratio (FCR) of 2.5 : 1 and 79% survival. A further 684 kg/ha of crawfish were harvested in year 3. During the warmer months (mid-May to mid-October) in Louisiana (USA) the culture of *M. rosenbergii* offers the opportunity for double cropping. Because of social structure problems, mixed sizes were obtained at prawn harvest.

12.2.5 Productivity

Information on the productivity of finfish and prawns in polyculture in the literature is sparse but typical ranges are summarised in Table 12.1.

Prawn productivity at the lower end of the range has been reported by Jose *et al.* (1992) and Hoq *et al.* (1996). Jose *et al.* (1992) described an experiment in which *M. rosenbergii* were stocked at a rate of 1/m^2 with catla, rohu and mrigal, which were introduced 3 months later at only 1000/ha in the ratio 2 : 2 : 1, in a range of 100 to 120 m^2 manured and fed homestead ponds. This resulted in a gross yield of 106 to 254 kg/ha of prawns and 297 to 408 kg/ha of fish, which offered a potentially increased income to operators, despite these figures being lower than average (Table 12.1). Hoq *et al.* (1996) reported that the yield of prawns after 10 months of rearing in polyculture varied from 162 to 428 kg/ha. However, finfish (five Chinese and Indian carp species) production ranged from 4604 to 5821 kg/ha. At the other extreme, Ninawe (1994) made some very optimistic predictions of prawn farming potential in India, both for monoculture and polyculture. This author claimed that, despite the very low production at the village level, it would be possible to produce 19 t of prawns and 15 t of fish/ha annually under intensive conditions! Following trials of prawns cultured with carps in the Andaman Islands (also in India), Sarangi *et al.* (1998) concluded that this would improve aquaculture productivity in ponds with low pH. Productivity ranged from 198 to 257 kg/ha in 195 to 224 days, with individual prawn weights at harvest ranging from 40 to 150 g.

In Rio Grande do Sul (sub-tropical Southern Brazil) about 1000 kg of *Macrobrachium* and 5000 kg of fish/ha can be produced in six summer months. In the same region, other traditional common carp farms are introducing prawns at low densities (0.5–1.0/m^2) into their fishponds, obtaining a higher-value product (crustaceans) with an additional yield of 350 to 600 kg/ha. Rodrigues (1994) experimentally obtained 360 kg/ha of prawns in polyculture with common and bighead carps with a prawn average weight of 62.3 g, utilising stocking densities of 2 to 3 PL/m^2.

Sadek & Moreau (1996) reported that prawn biomass (claw-off) averaged 432 to 1407 kg/ha in monoculture and 360 to 462 kg/ha in polyculture. Polyculture added 1826 to 3361 kg/ha of fish to prawn production. These authors reported an average harvest weight (claw-on) of 33.0 to 44.4 g in monoculture and 35.4 to 40.2 g in polyculture after 90 to 99 days of culture. As noted in section 12.2.3, Siddiqui *et al.* (1996) obtained a yield of prawns in monoculture (1152 kg/ha) which was significantly greater (1.62 times) than that from polyculture (711 kg/ha). However, total yield from polyculture including tilapias (2544 kg/ha) and common carp (2999 kg/ha) was almost five times as great as from prawn monoculture.

Perry & Tarver (1987) compared the performance of *M. rosenbergii* in monoculture or in polyculture with golden shiners (*Notemigonus crysoleucas*). This trial revealed that stocking shiners at 24 700/ha with prawns at 4.4/m^2 resulted in increased total pond production, compared with prawns stocked in monoculture at 4.4/m^2. Equal prawn yields were achieved in both systems with little increase in labour. The polyculture of shiners with prawns added an average of 307 kg/ha of the bait fish to pond production.

12.2.6 Profitability

Many polyculture studies cover profitability, usually in combination with a discussion of yield. In most cases, the polyculture of prawns in ponds appears to be beneficial (see, for example, Costa-Pierce *et al.* 1987; Scott *et al.* 1988; Davis 1990). On the other hand, tilapia, which were inadvertently introduced into prawn ponds in Hawaii, have been described as 'pest fish', causing serious competition for food (Brock 1988). Tilapias were also grown in cages in freshwater prawn ponds in Puerto Rico but this practice was described as a 'disaster' (J. Glude, pers. comm. 1993) because of escapees, which took years to eradicate. However, the polyculture of artificially incubated sex-reversed caged tilapias in *Macrobrachium* ponds, which would solve this potential problem, has been under trial in Brazil since 1997 (S. Zimmermann, pers. comm. 1999). A few examples of claims about the profitability of prawn polyculture in various countries are provided in this section. However, detailed studies of the economics of any form of grow-out system of freshwater prawn culture are scarce (see Chapter 20); thus, some caution is advisable in making assumptions about the profitability of polyculture.

In a study which evaluated the profitability and technological acceptability of fish–prawn polyculture in Bangladesh, Hoq *et al.* (1996) stated that cost–benefit ratios ranged from 1.34 to 1.92 with 33.8 to 92.3% economic returns on investment. One farmer in Southern Brazil is reported to have increased his net income by 30% after introducing grass carp into *M. rosenbergii* ponds (M. Azevedo, pers. comm. 1994). Previously, several farmers had noticed that prawns produced in polyculture with fish had a smaller size variation (Zimmermann 1991). D'Abramo *et al.* (1986) reported the same phenomenon. Hepher & Pruginin (1981) noted high growth rates and feed savings as advantages of using grass carp in polyculture with prawns. In addition, the waste 'green-pellet' – partially digested forage – is appreciated by prawns. Adisukresno *et al.* (1982) also registered an increase in prawn productivity, 550 to 2250 kg/ha/yr, by introducing phytoplanktophagous fish, such as Nile tilapia and silver carp, in Indonesian ponds. Carvalho *et al.* (1998), having tested the economic feasibility of culturing *M. rosenbergii* with common carp in Northeastern Brazil, concluded that polyculture gave the best economic result when compared to the monoculture of either carps or prawns.

Bo *et al.* (1995) reported that *M. rosenbergii* farmed in low salinity (6–9 p.p.t.) ponds in China, together with mullets, generated an extra farm income of 68.3%, compared with farming prawns in monoculture. In a previous trial, Dong & Zhang (1993) had obtained similar results in an experiment where *M. rosenbergii* were monocultured or polycultured with silver carp, bighead carp, grass carp and mullets. The output from monoculture was 145 kg/mu (2175 kg/ha), while the polyculture of *M. rosenbergii* with fish produced 224 kg/mu (3360 kg/ha) and increased the economic benefit of polyculture by about 300 yuan/mu (US$ 5445/ha) above that of monoculture. Sadek & Moreau (1996) reported that estimated net income/ha varied from US$ 946 to 7102 in an experiment comparing various monoculture and polyculture (with tilapia and carp) systems in Egypt. Highest rates of return were found in high-density monoculture when juveniles were stocked (57.5%), and in low-density polyculture when 2 PL/m^2 and 1.25 fish/m^2 were stocked (30.9%). Sadek & Moreau (1998) also investigated the economics of the polyculture of prawns and tilapia in rice paddies (see section 12.3).

A net income of US$ 5309/ha and US$ 4095/ha from a 180-day production of 1045 kg/ha of prawns and 2700 kg/ha of tilapias, respectively, was reported in Israel by Mires (1987). Hulata *et al.* (1990) reported (see section 12.2.3) that the gross income from prawns in polyculture, calculated on differential values according to harvest size, ranged from US$ 4207 to 4376/ha. Sarig (1992) showed that income from ponds stocked with common carp and/or tilapia (*O. aureus* × *O. niloticus*) could be increased by 17 to 47% by stocking *M. rosenbergii*, without any detrimental effect on fish production.

Engle (1987) examined the economics of two polyculture systems in Panama: tilapia, grass carp and freshwater prawns; and pacu (*Colossoma mitrei*), grass carp and freshwater prawns, compared to the monoculture of prawns. All systems were economically feasible but internal rates of return ranged from 13% for the monoculture systems to 23% on the polyculture ones, leading to the conclusion that polyculture was preferable.

In South America generally, the introduction of freshwater prawns at low densities (2–3/m^2) into fishponds cost from US$ 200 to 840/ha/cycle in 1998, based on the typical PL costs in that continent (US$ 10–28/1000) at that time. Assuming that PL are the only extra operational cost in this procedure, it is possible to generate an additional income of US$ 1750 to 3000/ha/cycle, based on a production of 350 to 600 kg/ha/cycle. A similar situation was reported from Israel in the late 1980s, at the time when prawns were commercially cultured there (see Chapter 17). Despite the low productivity of prawns in the culture system (approximately 300 kg/ha), the income was twice as much as from fish, due to the high commercial value of the prawns (Z. Ra'anan, pers. comm. 1989).

12.3 Integration of prawn culture with crop production

As noted by New (1995), the feasibility of using the wastewater from fish–prawn polyculture for the irrigation of tree crops and other crop production on the bunds of prawn ponds is not uncommon. This author also noted that, in Puerto Rico, prawns had been shown not to depress rice production when grown together, a practice also reported in Japan and Southern Brazil. A pilot study on a channel catfish/prawn/red swamp crawfish rotation with rice production was also reported to have been carried out in the USA. In Hawaii, Costa-Pierce (1987) used the outlet water from a polyculture experiment to irrigate 0.79 ha of papayas (*Carica papaya*), hybrid bananas cv. Williams (*Musa* sp.), and avocados Yamigata (*Persea americana*). A similar study was conducted by Pandian (1987) in India.

Preliminary work by Chattopadhyay *et al.* (1995) described a two-phase rice-aquaculture experiment in West Bengal (India). In the monsoon season, the culture of *M. rosenbergii* with the Indian carps rohu, catla and mrigal, together with exotic fish species (silver carp and the Java carp, *Puntius javanicus*), was combined with the farming of a semi-salt-tolerant rice strain. In the dry season (April–June) the area was used solely as a pond, filled from a local estuary, for rearing mullet (*Liza parsia*) and marine shrimp (*Penaeus monodon*). Due to the flushing efficiency of the monsoons, soil salinity showed no increasing trend, even after 5 years. Annual yields of 3.3 t/ha of rice were complemented with 0.43 t/ha from brackishwater aquaculture and 0.44 t/ha from freshwater aquaculture.

Sadek & Moreau (1998) evaluated the technical and economic feasibility of cultivating freshwater prawns (*M. rosenbergii*), either stocked alone at two densities (1 PL/m^2 and 2 PL/m^2) or stocked at 1 PL/m^2 with 5000/ha of Nile tilapia (*O. niloticus*) in rice fields in Egypt. The maximum net return achieved was US$ 4507/ha, which was obtained in the rice–prawn culture at the higher prawn stocking density. Rice alone gave the lowest net return (US$ 904/ha), while the rice–prawn–fish system was intermediary.

Eversole & Pomeroy (1988) reviewed the potential of rice–prawn culture in Asia and drew comparisons with crawfish–rice culture in the USA. Janssen *et al.* (1988) investigated the possibility of combining prawn culture with rice production by stocking PL60 *M. rosenbergii* in trenches dug around Thai rice fields. PL1 prawns were nursed to PL60 in ponds prior to stocking. About half of the prawns reached marketable size within 3 months when stocked at 1.25/m^2. Rice–prawn culture was the subject of a trial by Das *et al.* (1991) in India. These authors used pens made from woven bamboo splicings and stocked them with *M. rosenbergii*, together with rohu, common carp and Java carp, in deepwater rice fields. Roy *et al.* (1991) integrated prawn culture in deepwater rice fields with vegetable production and showed that rice production was increased by the presence of fish and prawns. Deepwater rice fields are not feasible in all regions. For example Southern Brazil, which is a major intensive and mechanised rice production area, employs modern rice varieties which are very short-stemmed and require shallow water.

A paper by Lightfoot & Nguyen (1990), which deals primarily with effective methods of aquaculture extension, reported that the income from prawns in integrated rice–prawn culture can be two or three times as great as that from rice monoculture. While the introduction of freshwater prawns reduces the area devoted to rice paddy by 15%, it also reduces weeding costs by about 33% (prawns eat weeds), and reduces fertilisation costs by 28% without lowering rice yield.

Rice–prawn and vegetable–prawn culture are now commonplace in Vietnam (Fig. 12.1). The major period of freshwater prawn growth is in the monsoon season, May to October (Lin & Lee 1992). Wild-caught 2 to 5 g prawns are stocked in rice fields with peripheral trenches 2 to 3 m wide and 1 m deep (sometimes with transverse or diagonal ditches in large fields) at 1 to 2/m^2 during the culture of the first rice crop in the early part of the year. Prawns are given a supplemental feed of rice bran mash. Harvests of 200 to 400 kg/ha/yr are achieved, with a value of US$ 600 to 1200, much more than the value of the rice crop. Prawns were also reported to be stocked at 4 to 6/m^2 in rice fields with platforms and levées for growing cucumbers,

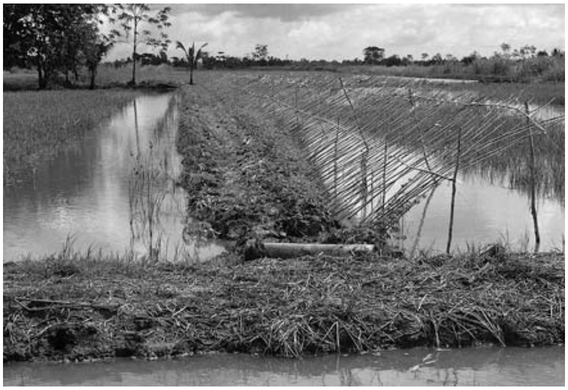

Fig. 12.1 Rice–prawn farm in Cantho Province, Mekong delta, Vietnam. Note: rice-growing areas are surrounded by peripheral canals which have been prepared for the culture of *Macrobrachium rosenbergii*. Vegetable crops are often grown on the canal dykes. In this farm, a bamboo structure has been erected which is used to support cucumber vines. (Source: Hien *et al.*, 1998, by permission of Japan International Research Center for Agricultural Sciences [JIRCAS].)

string beans, eggplants and banana, and fed with a rice bran/cassava chips/trash fish diet. The yield from this form of integration was said to be around 500 kg/ha in 6 months, with a gross annual income three or four times that achieved from the use of the area for rice production alone.

In a review of rice–prawn culture in Vietnam, Hien *et al*. (1998) stated that prawn productivity was typically 150 to 180 kg/ha and that rice production was enhanced by such integration. Nguyen *et al.* (1993) studied 42 private rice-based farms in Vietnam into which *M. rosenbergii* had been introduced. Prawns were reared in both rice–prawn systems and in garden trenches supplying fruit trees and vegetables. Annual rice production averaged 8.5 t/ha from two crops and a prawn yield of 354 kg/ha was obtained from a single annual crop. Rice contributed 42% to net farm income and prawns contributed 32%. Rice was destined for domestic markets but prawns were sold as a high-value cash crop for export and yielded 43% of the cash income, compared with only 20% from rice. For a small increase in labour, a 72% increase in net farm cash income was produced. Cassava chips, coconut waste and leftovers of broken rice and bran from milling were used as prawn feed, and enriched mud from trenches was used as garden fertiliser. More than 25% of the 4 million ha Mekong delta is affected by the oxidation of potentially acid soils. The introduction of prawns and better water management alleviated this problem in the farms studied.

Nguyen *et al.* (1993) proposed a method to examine the sustainability of this form of aquaculture. These authors noted some problems, which were caused by the predation of prawns by fish and humans, shortages of fry, and water pollution due to the heavy use of farm chemicals in the delta for the production of high-yielding rice varieties. Similar problems in Vietnam had been reported by Le (1992), who recommended the establishment of nurseries to rear prawns to 4 to 5 g before stocking for grow-out. In addition to the feeds mentioned by Nguyen *et al.* (1993), Le (1992) noted the use of trash fish, shrimp head wastes and fiddler crab (*Uca* sp.). One to two prawns/m^2 were being stocked in rice fields with peripheral ditches; water levels ranged from 0.15 m in the rice fields to 1.2 m in the ditches. Juvenile prawns were stocked 15 to 20 days after rice transplanting. Reported problems included poor management, low pH, and predators. Nguyen (1993) stated that farmers may obtain as much from selling 1 kg of size 1 (>70 g) prawns as from selling about 70 kg of paddy rice. However, farm-gate prices were reported to be unstable and to suffer from gluts at peak harvesting periods.

Hien *et al*. (1998) reported that rice–prawn integrated farming could be made more effective by combination with polyculture. Indeed Vietnamese farmers were said to be already stocking silver carp, tilapia, and common carp, as well as *M. rosenbergii*, in their rice fields. Irrigated rice fields were experimentally used for grow-out to market size and also as nurseries for rearing *M. rosenbergii* PL to juvenile size, prior to stocking in grow-out ponds in Indonesia, by Hadidjaja & Yunus (1994). However, the growth rate of PL in rice-field nurseries was low, compared to that in nursery ponds.

In areas of Vietnam where only one rice crop is possible because the salinity of rivers and canals is too high for growing rice during the dry season, the addition of *M. rosenbergii* to an integrated system may be beneficial, as shown by experiments in the north Can Gio District of Ho Chi Minh City carried out by Lai *et al*. (1998). In these experiments in crustacean–crop integration, which were conducted in three fields (0.4, 0.5, and 0.6 ha), rice was planted in mid-June, freshwater prawns were stocked ($1.5/m^2$) at the end of June, the rice was harvested in mid-November, and freshwater prawns were harvested in early February. In one field, marine shrimp (*P. monodon*) were also stocked ($1.5/m^2$) in mid-February and harvested in early June (just before the rice planting of the second year). Yields ranged from 2.9 to 3.4 t of rice and 434 to 596 kg/ha of freshwater prawns (average individual weights ranged from 62 to 76 g). In the one field where tiger shrimp were stocked, an additional 390 kg/ha of shrimp was harvested (mean weight 42 g). The authors stated that 1000 ha was available for this type of crustacean–crop integration in the district where the experiments were conducted, and that this form of farming represented a low-investment, high-revenue, no-pollution opportunity. The farmed crustaceans used natural food until the final month of culture, when supplemental food was supplied.

12.4 General conclusions

Freshwater prawns clearly have a role to play in successful commercial polyculture and integrated aquaculture, which is already being exploited in some countries (notably Brazil, China and Vietnam) and has been the subject of experimentation in many others.

Stocking prawns in polyculture with finfish has the potential of increasing total yield as well as farm income, particularly as prawns have a higher commercial value than most finfish. Some ecological advantages of polyculturing finfish with prawns, such as improved water quality (thus potentially reducing water exchange), increase the sustainability of this form of aquaculture. However, while the polyculture of prawns with finfish is quite common in farming practice, scientific studies on this subject present a rather confused and incomplete story, which requires elucidation.

The addition of prawn culture to rice farming is ecologically sound and a good method of diversification. The integration of prawn with rice culture has decreased the utilisation of chemical fertilisers and pesticides in Asia. This has also been noted in Southern Brazil where major prawn farms are very close to rice fields. Thus, prawns predate insects, improve soil fertility and feed on the seeds of common rice-field weeds. However, the expansion of prawn–crop integration is constrained, in both Asia and Latin America, by lack of technology transfer, shortages of prawn seed, and capital to develop and improve feeding systems and marketing deficiencies.

12.5 References

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13
Nutrition, Feeds and Feeding

Louis R. D'Abramo and Michael B. New

There is a considerable amount of information concerning the qualitative and quantitative nutritional requirements of the freshwater prawn *Macrobrachium rosenbergii*. The topic has been the subject of several reviews, which include New (1976), Biddle (1977), Sick & Millikin (1983), D'Abramo & Sheen (1994), Fox *et al.* (1994), D'Abramo *et al.* (1997), New (1997), D'Abramo (1998), and Zimmermann (1998). Some nutritional requirements differ from those of other crustacean species; these are founded upon its omnivorous feeding habits, combined with the fact that most of its life span is spent in freshwater. Most of the information derived from classical nutrient requirement research has yet to be applied to the development of practical commercial diets for pond grow-out culture. This condition reflects the fact that grow-out systems for this species are predominantly pond based and semi-intensive. The management strategies of semi-intensive, pond-based culture permit secondary productivity to contribute substantially to satisfying nutrient requirements. However, as the resident biomass of freshwater prawns in a pond increases, normal levels of secondary productivity cannot sustain the nutritional needs for maximum growth, and additional food resources are needed. Farm-made or commercially manufactured diets are used to compensate for nutritional deficiencies, serving either as a direct supplemental source of nutrients or as an indirect source by enhancement of the natural productivity of the pond.

The first parts of this chapter focus on nutritional physiology as well as age-dependent nutritional requirements derived from classical nutritional experiments. Following this, the results of studies concerning the suitability of particular dietary ingredients and use of commercial feeds are reviewed. The chapter concludes with a discussion of farm-made feeds and the presentation of some formulations.

13.1 Diet and digestive physiology

The study of Tidwell *et al.* (1995) provides insight into the dietary preferences of freshwater prawns relative to the benthic invertebrate populations inhabiting earthen ponds. When a nutritionally incomplete diet was provided, macroinvertebrate populations were reduced by approximately 70%, presumably the result of consumptive predation by prawns. The greatest proportional decrease in resident benthic populations was observed for oligochaetes followed by insects, gastropods, chironomids, pelecypods, and nematodes. The reductions in density were significant for all taxa. Using stable carbon isotope analysis, Schroeder (1983) found that *M. rosenbergii* feeds on a variety of foods consisting of chironomids, rock slime organic matter, and microalgae. Analyses of stomach contents to determine dietary preferences of freshwater prawns reared in nursery and grow-out ponds have confirmed that prawns are omnivorous and principally bottom feeders (Correia 1998a). More than 75% of the stomachs examined contained plant matter and sand, 65% contained microalgae, and 57% contained organic matter. Macroalgae (23%), insect remains (13%) and molluscan remains (10%) were also observed. Correia (1998b) observed that fertilised semi-intensive managed ponds provide more natural food organisms for prawns than either unfertilised or intensively managed ponds. Lilyestrom & Romaire (1987) found the per cent occurrence of macroalgae and insecta to be 37.9% and 13.7%, respectively, in the stomachs of prawns collected during May to October from ponds where channel catfish were jointly cultured. Tidwell *et al.* (1995) found that when neither organic fertilisation nor a pelleted diet was provided to pond populations of prawns, the total population of macroinvertebrates in the ponds was significantly reduced.

Plant material of the proper quality appears to be nutritionally beneficial. Harpaz & Schmalbach (1986) found that supplementation of fresh leaves of *Ailanthus altissima* (Simaroubaceae) and *Malva parviflora* (Malvaceae) to a formulated diet fed to adults of *M. rosenbergii* reduced the incidence of black spot disease and eliminated a moult death syndrome. These results suggest that natural sources of plant material may serve as good sources of vitamin C, a required nutrient (see section 13.2.2.4).

Characterisation of the activities of digestive enzymes of *M. rosenbergii* strongly suggests that this species is an omnivore, the natural diet consisting of a variety of plant and animal material (Lee *et al.* 1980). The freshwater prawn has a broad array of proteolytic enzymes, including carboxypeptidases A and B, leucine aminopeptidase and trypsin, for chemical digestion of its natural food. These investigators originally reported the presence of pepsin but this finding appears to be incorrect. Lipases and esterases have been identified but specific metabolic roles have not been determined. Chuang *et al.* (1985) have found that cellulase activity in *M. rosenbergii* exceeds that of each of five species of marine shrimp. Chitinases have also been reported for *M. rosenbergii*. An amylase is the only digestive carbohydrase to have been reported. Presumably carbohydrase activity for the freshwater prawn is comparatively higher than that of carnivorous species of shrimp. All of the digestive enzymes originate in the midgut gland (often referred to as the hepatopancreas) where a number of other metabolic activities in decapod crustaceans occur (Ceccaldi 1997). The enzymes are emptied into the anterior portion of the small intestine where most of the intra-lumen digestion occurs. Observed regurgitation of food by prawns is believed to increase feed efficiency by decreasing the amount of energy needed to transport unassimilable material through the entire digestive system (Newman *et al.* 1982).

13.2 Nutrient requirements

13.2.1 Larvae

In the absence of a nutritionally complete, formulated diet that would exclusively sustain growth throughout all eleven larval stages until metamorphosis into postlarvae (PL), information about quantitative nutritional requirements of larvae is difficult to obtain. The lack of success with formulated diets, particularly during early stages of development, may reflect the unique inability to produce sufficient amounts of digestive enzymes (Jones *et al.* 1993). Achieving success with formulated diets may not be possible until the midgut gland begins to function, during stages VI or VII. Provision of an exogenous source of enzymes may be necessary to achieve good growth and survival during the early developmental stages. Live or frozen, newly hatched *Artemia* nauplii are generally the diet of choice for larval culture. During the latter stages of development, the *Artemia* are often supplemented with commercially manufactured or farm-made diets of suitable size for consumption. *Artemia* nauplii contain comparatively high levels of protein and lipid, 55% and 21%, respectively (Gallagher & Brown 1975). Protein and lipid would be expected to be the exclusive or almost exclusive sources of energy for larvae; therefore, requirements for these macronutrients are probably higher than those of juveniles and adults and are suitably served by *Artemia* nauplii. The recognised nutritional value of *Artemia* is also embodied in its essential amino acid profile, which is similar to that of juvenile *M. rosenbergii.*

Roustaian *et al.* (1999) observed changes in the fatty acid composition of larvae of *M. rosenbergii* during the different stages of larval growth. At stage I, prior to feeding, development appears to be dependent upon the use of maternally derived saturated (16:0 and 14:0) and monounsaturated (18:1, 16:1) fatty acids, and 18:2 n–6 (linoleic acid) as sources of energy. Thereafter, the fatty acid profile reflects that of the *Artemia* diet and is characterised by an increase in n–3 fatty acids to levels that either increase or remain stable throughout larval development. Some of the results suggest that the larvae have the metabolic ability to biosynthesise 18:2 n–6 (linoleic acid) to 20:4 n–6 (arachidonic acid) and 18:3 n–3 (linolenic acid) to 20:5 n–3 (eicosapentaenoic acid). A dietary requirement for highly unsaturated fatty acids (HUFAs) was demonstrated by Deru *et al.* (1989). Larvae fed *Artemia* nauplii containing high levels (6.0%) of n–3 HUFAs had significantly greater survival and growth than larvae fed *Artemia* containing lower levels (0.3%). The low growth and survival of prawns fed *Artemia* with the low level of HUFAs were eliminated when a period of pre-feeding microcapsules containing high levels of n–3 HUFAs was incorporated into the culture protocol. A requirement for n–3 HUFAs is not unexpected given the brackishwater requirement for successful larval culture. Larval prawns fed n–3 HUFA-enriched *Artemia* exhibit earlier and more synchronous metamorphosis (Devresse *et al.* 1990), two characteristics which reduce the overall operational costs of larval culture. Cavalli *et al.* (1999) found that docosahexaenoic acid (22:6 n–3) was used as a major source of energy during the early stages of development of the larvae. Therefore, the choice of an *Artemia* cyst product to be used in the culture of larval prawns should consider the levels of n–3 HUFAs in the tissue of the newly hatched larvae. Provision of adequate dietary levels of vitamin C also appears to be important. Larvae fed *Artemia* enriched with vitamin C tend to be more tolerant of stressful conditions. Chapter 7 contains a detailed discussion of these topics. Exuvia entrapment disease (EED), a possible nutritional deficiency disease affecting not only larvae but also juveniles and adults, is discussed in Chapter 15. Exuvia entrapment disease was described in lobsters by Bowser & Rosemark (1981) and was termed moult death syndrome (MDS). Recently, Wang & Qianhong (1999) referred to this syndrome in freshwater prawns as 'ecdysis-obstacle disease'.

13.2.2 Juveniles

The bulk of information about the nutrition of *M. rosenbergii* has been derived from investigations with juveniles under controlled laboratory conditions. Generally, management strategies associated with commercial production of *M. rosenbergii* consist of a 30- to 60-day indoor or outdoor nursery phase of culture in ponds or tanks (Chapter 8). The high density associated with nursery culture and the desired healthy condition of the juveniles for stocking into grow-out ponds may warrant use of a nutritionally complete diet, most definitely in tank culture without a mud bottom.

Juveniles probably require less dietary protein than larvae. Due to the short duration of the nursery phase and the comparatively small amounts of diet needed, higher cost, commercially manufactured diets containing high levels of protein and lipid, such as trout diets, are not economically prohibitive. These diets have routinely yielded good growth and survival when supplemented with frozen liver at levels of 15 to 25% (dry weight [DW]) of the diet (D'Abramo *et al.* 1995; Molina-Vozzo *et al.* 1995).

13.2.2.1 Protein requirement

Freshwater prawns appear to require the same 10 essential amino acids as other crustacean and fish species. Watanabe (1975) used isotopic precursors to determine qualitative requirements for arginine, histidine, isoleucine, leucine, methionine, phenylalanine, tyrosine, and valine. There is some evidence that *M. rosenbergii* may lack the ability to biosynthesise asparagine (Smith *et al.* 1987). Experiments with other aquatic species have demonstrated that amino acid requirements, expressed as a per cent of dietary protein, are closely associated with the relative proportions found in their muscle tissue (Cowey & Tacon 1983; Wilson & Poe 1985). Guidance about the potential quality of a dietary protein source or mixture of sources can be obtained from whole body essential amino acid profiles which are in turn used to produce an evaluative index such as A/E. This index is based upon the calculation of the relative proportion of each essential amino acid (A) to total essential amino acids (E). D'Abramo (1998) compared A/E indices of tail muscle and whole body tissue of juvenile *M. rosenbergii* with those of *Penaeus monodon* and *Penaeus* (*Marsupenaeus*) *japonicus*. The relative proportions of the essential amino acids are very similar between tissue and among the species (Table 13.1). If one or more dietary A/E ratios conspicuously deviate from those found in the tissue, then the dietary imbalance will probably be expressed through a reduction in growth rate. The

Table 13.1 Comparison of the ratio of total to essential amino acid content of whole body and tail muscle tissue (A/E indices) in *Macrobrachium rosenbergii* and two marine shrimp species. (Source: D'Abramo, 1998.)

	Macrobrachium rosenbergii		*Penaeus monodon*		*Penaeus* (*Marsupenaeus*) *japonicus*	
Amino acid	Tail	Whole body	Tail	Whole body	Tail	Whole body
Arginine (Arg)	190	146	183	153	nd	152
Histidine (His)	46	68	42	47	nd	45
Isoleucine (Ile)	82	73	86	85	nd	86
Leucine (Leu)	147	148	146	146	nd	150
Lysine (Lys)	166	164	150	145	nd	158
Methionine (Met)	60	70	65[a]	74[a]	nd	75[a]
Phenylalanine (Phe)	148	172	142	155	nd	168
Threonine (Thr)	81	88	71	76	nd	82
Tryptophan (Typ)	nd	nd	21	16	nd	nd
Valine (Val)	82	73	99	100	nd	83

[a] Includes cystine.
nd = not determined.

relative proportions of protein sources in diets prepared for *M. rosenbergii* can be manipulated to achieve the 'ideal' A/E ratios.

To obtain maximum growth, a single protein source or a mixture of protein sources must be provided at appropriate levels and proportions such that the requirements of all essential amino acids are satisfied. The most likely amino acids to be limiting in feedstuffs provided as protein sources are arginine, lysine, and methionine. A particular protein source or group of protein sources which are substantially deficient in one or more essential amino acids will be required in greater amounts to achieve a maximum growth rate or weight gain response. Accordingly, the 'protein requirement' will be greater for a diet composed of such 'inferior' protein sources. Experiments which have evaluated combinations of protein sources or essentially single protein sources with a good amino acid profile (A/E indices highly comparable to those of muscle tissue) and high digestibility suggest that the minimum 'protein requirement' of juvenile *M. rosenbergii* is approximately 30 to 35% of the diet (Balazs & Ross 1976; Millikin *et al.* 1980; Freuchtenicht 1987; Reed 1987). This requirement is based upon satisfaction of the essential amino acid requirements for growth plus any protein that may be required/used as a source of energy. Experiments suggest that the amount of dietary protein used as an energy source can be substantially reduced (spared) through the provision of the proper levels and types of dietary carbohydrate and lipid. Therefore, under these conditions, the amount of dietary protein needed to achieve maximum growth can be reduced because almost all dietary protein is channelled to tissue deposition. Dietary protein requirements may be age specific.

The most efficient utilisation of dietary ingredients is also dependent upon the dietary protein/energy ratio because the amount of non-protein energy ultimately affects the amount of diet which is consumed. Also, if diets contain low amounts of available non-protein energy, protein (P) which potentially could be used for growth has to be used to obtain energy (E). Summerlin (1988) found that a P:E ratio between 130 to 158 mg protein/kcal yielded the highest weight gain of *M. rosenbergii*. However, this range of values was determined without applying apparent digestibility values to the dietary protein, lipid, and carbohydrate sources. Most of the optimum dietary P:E ratios for marine shrimp fall within the range 110 to 130 mg protein/kcal. Clifford & Brick (1978) indicated that the use of protein as an energy source by juvenile freshwater prawns was minimised at a 1:4 ratio of lipid to carbohydrate. Gomez Diaz *et al.* (1988) found growth and survival to be highest at a dietary protein:starch ratio of 1:1.

13.2.2.2 Triglyceride, cholesterol, and phospholipid requirements

The freshwater prawn has no fixed dietary lipid requirement. The required amount is essentially based upon satisfaction of the requirements for essential fatty acids, in combination with its supply as a good source of energy to spare (reduce) dietary protein requirements. With a good source of dietary protein, levels of dietary lipid which contain the appropriate levels of essential fatty acids can be as low as 2% (Sheen & D'Abramo 1991), particularly if dietary carbohydrate sources can be effectively used as sources of energy. When a 2:1 mixture of cod liver oil and corn oil was fed at dietary levels ranging from 2 to 10%, weight gain of juvenile *M. rosenbergii* was not significantly different. Maximum, although not significantly greater, weight gain was achieved at a level of 6%. Dietary lipid levels which exceed 10% are generally associated with a reduction in growth rate, possibly due to the inability to process such high levels. Querijero *et al.* (1997a,b) determined that dietary stearic acid (18:0) and oleic acid (18:1) are used as sources of energy. Per cent weight gain was significantly reduced when the dietary level of oleic acid was increased from 1 to 8%.

Freshwater prawns appear to require polyunsaturated fatty acids of C18 and C20 length (D'Abramo & Sheen 1993). Juvenile prawns are unable to synthesise either linolenic (18:3 n–3) or linoleic (18:2 n–6) acids (Reigh & Stickney 1989). D'Abramo & Sheen (1993) added these fatty acids, either individually or in different proportions, to semi-purified diets containing no other polyunsaturated fatty acids (PUFAs) or HUFAs. No significant increase in weight gain of prawns fed these different diets was observed. Reigh & Stickney (1989) found a similar lack of growth responses to 1% additions of either 18:2 n–6 or 18:3 n–3 to a lipid-free diet. However, a requirement for these PUFAs may not be manifested through measurement of a weight gain response. In the absence of dietary 18:2 n–6 and 18:3 n–3, the size of the midgut gland relative to the whole body of juvenile prawns was significantly reduced (D'Abramo & Sheen 1993). Teshima *et al.* (1994) found that *M. rosenbergii* fed diets containing a mixture of 18:2 n–6 and 18:3 n–3 had the highest weight gain. In this study, the optimum dietary ratio of n–6 to n–3 fatty acids was estimated to be about 20:1 but the optimal concentrations of 18:2 n–6 and 18:3 n–3 were not clearly established.

The capability of freshwater prawns to synthesise HUFAs from PUFAs, i.e. 20:5 n–3 and 20:4 n–6 from 18:3 n–3 and 18:2 n–6, respectively, is extremely limited (Reigh & Stickney 1989; D'Abramo & Sheen 1993). Results of the study of D'Abramo & Sheen (1993) suggested that 20:5 n–3 can be synthesised from 22:6 n–3; however, the capability of bioconversion in the opposite direction was found to be lacking (Teshima *et al.* 1992). Freshwater prawns require dietary HUFAs (D'Abramo & Sheen 1993), but at levels much lower than those reported for marine shrimp. Both n–3 and n–6 HUFAs (22:6 n–3 and 20:4 n–6) at a dietary level of 0.075% (DW) produced a dramatic increase in weight gain. An increase of dietary levels up to 0.6% did not result in any further significant weight gains. Thus, in contrast to marine species of shrimp, highly unsaturated essential fatty acids of the linolenic (n–3) family are not preferred over those of the linoleic (n–6) family. Tissues of wild adult *M. rosenbergii* contain levels of n–6 PUFAs and HUFAs which are conspicuously higher than those of n–3 PUFAs and HUFAs (Castell 1983; Chanmugam *et al.* 1983). The family of n–6 fatty acids is characteristic of organisms inhabiting freshwater environments. However, the prevailing need for salt water for the larval cycle may explain why dietary n–6 and n–3 HUFAs are equally effective in eliciting significant weight gain responses.

Macrobrachium rosenbergii, like other crustaceans, is presumably unable to synthesise sterols *de novo*. The requirement of the freshwater prawn for dietary cholesterol is approximately 0.5 to 0.6% (D'Abramo & Daniels 1994), a level within the range reported for other species of crustaceans. When dietary beta-sitosterol, a plant-derived sterol (phytosterol), was substituted completely for dietary cholesterol at a level of 0.6%, no significant differences in weight gain or survival resulted (D'Abramo & Daniels 1994). Ergosterol and stigmasterol were not effective substitutes for cholesterol. The sole presence of cholesterol in the tissue indicates that dietary beta-sitosterol is efficiently converted to cholesterol. This biosynthetic ability may possibly have arisen from the omnivorous feeding habits of the freshwater prawns. This ability to utilise one or other plant sterols means that properly formulated commercial diets for freshwater prawns are likely to require only a small amount of cholesterol, if any at all. Sherif *et al.* (1992) and Briggs *et al.* (1988) suggested that a dietary level of 0.12% is sufficient to satisfy the cholesterol requirement, but this amount does not take into account possible phytosterol contributions from plant-derived feedstuffs in the experimental diets. Teshima *et al.* (1997) reported a cholesterol requirement of between 0.11 and 0.26% and found levels of body cholesterol increased in prawns fed a cholesterol-free diet. This latter observation led them to conclude that *M. rosenbergii* was capable of *de novo* synthesis. However, the soybean oil ingredient in the diet is a source of phytosterols which could be the source of cholesterol in the body tissue.

A dietary requirement for phospholipids, particularly phosphatidylcholine (PC) in the form of soy lecithin, has been demonstrated for both larval and juvenile species of marine shrimp. The need for PC may be due to rates of synthesis which are too low to provide sufficient PC when growth rates are rapid. However, a significant growth-enhancing effect of dietary phospholipid, provided in the form of soy lecithin was not observed in three independent investigations conducted by Hilton *et al.* (1984), Kean *et al.* (1985), and Briggs *et al.* (1988). When lecithin was added at a level of 2% to either a casein-based diet or diets with soybean protein, Alaska pollack meal, or sardine meal as a protein source, no improvement in growth or feed efficiency of communally reared juvenile (0.05 g) *M. rosenbergii* was observed (Koshio *et al.* 1994). However, when prawns were reared individually, some effect was observed and these authors speculated that if the generally poor performance found under these conditions was due to stress, then supplemental PC might alleviate this phenomenon. Querijero *et al.* (1997b) also found that growth or survival of juvenile freshwater prawns was unaffected by the addition of soybean lecithin at a dietary level of 2%, but the value of these results is questionable because the duration of the experiment was only 40 days. Phosphatidylcholine is a major component of lipoproteins that are known to transport lipids, specifically cholesterol, from the liver to other tissues (Teshima 1997). Despite this metabolic relationship, Briggs *et al.* (1988) did not find any evidence of an improvement in growth and survival of *M. rosenbergii* through an interaction between dietary cholesterol and phospholipid. Examining the effect of different levels of phospholipids (0.8, 2.4 and 4.6%) in isolipid diets fed to three groups of eight female freshwater prawns (*M. rosenbergii*), Cavalli *et al.* (2000) found no significant differences in fecundity, egg size and hatchability, starved larvae size, or in size, survival and tolerance to stress of 8-day-old larvae. This work tends to support the contention that freshwater prawns do not need supplementary dietary phospholipids. Any requirement is likely to be satisfied by the phospholipid-containing ingredients in commercial diets.

13.2.2.3 Dietary carbohydrates

There is no fixed dietary requirement for carbohydrate but *M. rosenbergii* does use dietary carbohydrates as sources of energy. The total amount of dietary carbohydrate which can be effectively utilised by the freshwater prawn is generally dependent upon digestive capability (level of enzymatic activity) and may exceed that of species of marine shrimp. The comparatively higher rates of production of amylases found for *M. rosenbergii* may be a product of its omnivorous feeding habits. Complex dietary polysaccharides (i.e. soluble starch, potato starch, dextrin, and alpha starch) are utilised better and yield higher growth rates than di- and monosaccharides (Gomez Diaz & Nakagawa 1990; Briggs 1991), a nutritional characteristic shared by marine shrimp and all species of fish studied up to now. Querijero *et al.* (1997c) found that dextrin and corn starch were good sources of dietary energy. In laboratory experiments where the level of dietary fibre reached 30% (DW), growth of *M. rosenbergii* was unaffected (Fair *et al.* 1980). Cellulose may actually serve as a source of energy (Briggs 1991) rather than being nutritionally inert as once assumed.

13.2.2.4 Vitamin and mineral requirements

Vitamin requirements of freshwater prawns are most probably similar to those determined for other aquatic species because vitamins serve as metabolic catalysts for the same chemical reactions. Nevertheless, experimental determinations of qualitative and quantitative vitamin requirements are difficult. Potential contributions from gut microflora interfere with obtaining accurate determinations, particularly for experiments of short duration. In addition, due the water soluble nature of many vitamins, precise control over dietary levels provided in unbound form is not possible due to losses from leaching. The rate of leaching is exacerbated by an increase in the relative surface area of the particles caused by the breaking up of food particles by the prawns, combined with an intermittent feeding activity. For most vitamins, clinical symptoms of deficiencies are difficult to recognise or are not manifested externally. Heinen (1984) observed significant mortality in the absence of either dietary vitamin C or pyridoxine. The only published quantitative vitamin requirement for *M. rosenbergii* is for vitamin C. D'Abramo *et al.* (1994) estimated the dietary vitamin C requirement to be approximately 100 mg/kg, a level that is consistent with reported vitamin C requirements of species of marine shrimp.

Investigations addressing quantitative mineral requirements of *M. rosenbergii* are lacking. Rath & Dube (1994) found that the best response (specific growth rate and feed conversion ratio [FCR]) to a range of levels of dietary zinc was at 90 mg/kg. For the freshwater phase of the life cycle of *M. rosenbergii*, satisfying the requirements for calcium and phosphorus is essential to growth. Any dietary calcium deficiencies for marine shrimp are most likely overcome by uptake from salt water. However, for organisms living in freshwater, calcium cannot always be readily obtained from the water because a wide range in the concentration of calcium exists within different bodies of water. Zimmermann *et al.* (1994) found that inclusion of dietary calcium is important when the concentration of this mineral in water is low (soft water). These authors used diets with a 1.5 : 1 ratio of calcium to phosphorus at dietary levels of either 3.0 or 1.8% calcium, and $CaCO_3$ was introduced into the culture water at levels of 23, 51, and 74 mg/L. Best survival and weight gain were obtained at a dietary level of 3.0% calcium, and a water concentration of 51 mg/L $CaCO_3$. Response of the diets containing 1.8% calcium was highest at the highest level of calcium added to the culture water. There is no information available concerning the dietary requirement for the other macromineral, phosphorus.

13.2.3 Adults and broodstock

The nutrition of broodstock *M. rosenbergii* has not received the same level of attention as that of marine shrimp. Information about specific nutritional requirements is limited and probably results from the lack of a need for routine maintenance of captive broodstock in many commercial hatcheries. Eggs can be easily hatched from females obtained from either grow-out ponds or capture fisheries. Broodstock nutrition would probably become a focus of research if interest in domestication through genetic improvement develops. In addition, the knowledge that the nutritional history of broodstock influences the health and performance of larvae underlies the importance of understanding broodstock nutrition, particularly as the need for consistency in commercial production arises. A practical broodstock diet is described in Chapter 4.

Broodstock of *M. rosenbergii* maintained in environmentally controlled conditions in England in 1969–1971 were fed formulated diets in which freeze-dried (chicken) egg was a major ingredient (M. New, pers. comm. 1999). Characteristically, these diets were very high in both protein and lipid content. D'Abramo *et al.* (1995) reported the successful use of a high-energy, high-protein (40%) salmonid (trout) diet for broodstock *M. rosenbergii*. The successful experimental use of diets formulated for broodstock *Macrobrachium* has also been reported by de Caluwé *et al.* (1995), Das *et al.* (1996), and Cavalli *et al.* (1999).

Das *et al.* (1996) evaluated 12 diets for the culture of broodstock. These diets were composed of different ingredients and contained different levels of gross energy, protein, and lipid. Based upon determinations of fecundity and per cent hatching rate of eggs for females fed each diet, the recommended brookstock diet contained 40% crude protein and a gross energy level of 400 kcal/100 g diet. The other diets which produced significantly higher levels of fecundity and per cent hatching rate contained 40% protein and a gross energy/protein ratio of 92 to 99. Increases in fecundity were realised when the levels of dietary fishmeal were increased to 16 to 18%. Dietary protein with an essential amino acid index similar to that of the eggs contributes to the overall quality of broodstock diets.

Cavalli *et al.* (1999) evaluated the effect of linoleic acid (18 : 2 n–6) and n–3 HUFAs on the reproductive performance and quality of offspring of *M. rosenbergii*. Dietary 18 : 2 n–6 increased fecundity and the addition of n–3 HUFAs resulted in increases in the gonadosomatic index, the weight of a clutch of eggs, and ultimately the number of eggs produced. Larvae hatched from females fed diets containing HUFA exhibited a higher level of tolerance to stressful conditions created by high levels of ammonia. However, manipulation of the level of dietary phospholipid in broodstock diets (Cavalli *et al.* 2000) had no significant effect on larval quality (see also section 13.2.2.2). Preliminary results indicate that 8-day-old freshwater prawn larvae may be more tolerant to stress if they originate from females fed diets high in vitamins C and E (R. Cavalli, pers. comm. 1999).

13.3 Grow-out feeds

13.3.1 Commercial and experimental feeds

The current semi-intensive or extensive nature of most of the grow-out culture of *M. rosenbergii* conducted globally has not warranted any urgent need for a species-specific, nutritionally complete diet. Grow-out feeds in most regions of the world are often farm-made (see section 13.3.2) rather than purchased from commercial manufacturers and, therefore, are not the product of an application of the existing body of knowledge of the nutritional requirements of *M. rosenbergii.* Most farm-made diets consist of a variety of ingredients such as trash fish, soybean meal, corn meal, vitamins and minerals, piglet and chicken feeds (Boonyaratpalin & New 1993). An effective farm-made feed is realised through an evaluative approach based on trial and error.

D'Abramo *et al.* (1995) have reported that commercially available 32% crude protein sinking catfish feed (Table 13.2) will adequately serve to promote growth during later stages of pond culture without a need for organic fertilisation. Melotti *et al.* (1989) also found that pelleted catfish feed yielded good growth and survival of prawns cultured in ponds at 2.8 and 7/m^2 (semi-intensive) when fed at a rate of 5% of the live weight daily. These catfish feeds most probably served as fertilisers rather than as direct sources of nutrition. If direct provision of nutrients is desired, precautions must be taken to ensure that the diet is sufficiently water stable. Stability increases the probability that the quantities of nutrients provided are ultimately available for consumption over a period of several hours. A number of commercially manufactured diets for freshwater prawns contain binders to enhance the physical integrity of the food. However, high inclusion levels of some binders have proved to be toxic to prawns (M. New, pers. comm. 1999). The physical integrity of diets may also be enhanced through the manufacture of an extruded diet. If the proper combination of desired ingredients is used, sinking diets can be produced by an extrusion manufacturing process. A by-product of the extrusion process may be an increase in the digestibility of starch or starch-containing ingredients, resulting in an increase in the availability of energy. The digestibility of starch by catfish was improved when diets were manufactured by an extrusion process (Wilson 1994).

Table 13.2 Ingredient composition of typical (32% crude protein) sinking catfish feed. (Source: National Warmwater Aquaculture Center, Stoneville, Mississippi [E. Robinson, pers. comm. 2000].)

Ingredient	Composition (%)
Soybean meal (48% crude protein)	51.25
Corn grain	28.55
Meat/bone/blood meal (65% crude protein)	4.00
Wheat middlings	10.00
Wheat grain	5.00
Dicalcium phosphate	1.00
Catfish vitamin mix[a]	0.10
Catfish mineral mix[a]	0.10
Total	100.00

[a] The vitamin and mineral mixes are commercially manufactured and formulated to meet the reported vitamin and mineral requirements of channel catfish (NRC 1983), except for vitamin C.

The observations on the stomach contents of cultured freshwater prawns by Weidenbach (1982) were convincingly confirmed by isotope studies on stomach contents conducted by Schroeder (1983). The latter study revealed that natural food items are preferred over formulated diets and contribute significantly to satisfying the nutrient requirements of *M. rosenbergii.* Therefore, recognising this feeding preference, more research should be directed towards the development of management practices which will optimise the availability of preferred natural food items.

Results from a more recent study conducted by Tidwell *et al.* (1995) revealed that the use of different feeds and feeding strategies produced differences in the levels of benthic prey organisms. The results of their study strongly suggest that prawns feed on macroinvertebrate populations, particularly when nutritionally deficient formulated diets are provided. Prawns grown in earthen ponds were fed either a nutritionally superior formulated diet, a supplemental diet in which the fish meal ingredient was entirely replaced and the vitamin and mineral mix ingredients were eliminated, or this supplemental diet combined with an organic fertilisation protocol. There were no significant differences in the growth of prawns fed the 'complete' diet and that of prawns fed the supplemental diet combined with fertilisation. A significant reduction in the density of benthic organisms was observed when the supplemental diet was fed exclusively, and the growth rate of prawn populations in these ponds was significantly lower than that of prawns fed the complete diet. Growth of prawns fed the supplemental diet was significantly higher when fertilisation was included as a pond management practice. These results suggest that fertilisation most probably serves to enhance secondary productivity, providing for an increase in available benthic food organisms to be consumed and to compensate for nutrient deficiencies. In the absence of fertilisation, the supplemental diet was not sufficient in meeting the nutritional needs of the prawn populations. Prawns which were fed the complete diet probably met their nutritional requirements with little or no need to forage on benthic organisms. The density of live benthic prey populations surveyed appears to be directly related to the level of predation which, in turn, is based upon the quality of the formulated diet provided and the resident biomass of the *M. rosenbergii* population. Lilyestrom & Romaire (1987) combined both visual and stable carbon isotope ratio analyses of stomach contents of *M. rosenbergii* grown in ponds with channel catfish. These authors found that the relative contribution of formulated feed to the growth of the prawns increased as the mean weight of the population (total population biomass) increased.

Given the current level of knowledge of the digestive physiology and nutrient requirements of freshwater prawns, the prospects for complete or at least partial substitution of marine meals and oils as dietary ingredients are good. Plant oils may be sufficient to satisfy fatty acid requirements but some ingredient must contain at least a source of an n–6 HUFA such as arachidonic acid.

The replacement of fish meal with soybean meal and a distillation waste product, distillers' dried grains and solubles, in diets for pond culture of the freshwater prawn has already been investigated (Tidwell *et al.* 1993). Three dietary treatments consisting of diets containing either 15, 7.5 or 0% menhaden fishmeal were evaluated. The reduction or elimination of fishmeal was compensated through the use of a fixed percentage (40%) of distillers' dried grains and solubles and a variable percentage of soybean meal to maintain crude protein levels at 32%. Average yield, survival, individual weight, and feed conversion were not significantly different among the dietary treatments. The successful elimination or reduction of the fishmeal as an ingredient may have been possible because any nutrient deficiencies which may result were eliminated through the consumption of natural food. Similar results may not be achieved at higher culture densities where the relative contribution from the consumption of natural food organisms would accordingly decrease. Koshio *et al.* (1992) found that soybean protein was a suitable substitute for crab protein concentrate in a diet fed to juvenile freshwater prawns fed under laboratory conditions.

When commercially manufactured diets are used, they are usually fed according to rates based upon per cent of the mean body weight of the prawns. The feeding rates recommended by D'Abramo & Sheen (1994) are based upon weight. The daily amount of diet provided per surface area of a pond for each week of culture is based upon these different feeding rates and the density (total biomass) of prawns derived from an estimated mortality rate of 2% per week. In experimental ponds where commercially manufactured feeds have been used, FCRs generally range from 2.5 to 3.5. Most probably, the FCRs do not reflect the direct contribution of the diets themselves, because most diets serve to enhance natural productivity, which, in turn, significantly contributes to the satisfaction of nutrient requirements and growth.

Commercial freshwater prawn feeds have been reported to contain protein levels that range from 23.8 to 38.5% in Hawaii (Corbin *et al.* 1983); 28 to 36% in Taiwan (Hsieh *et al.* 1989); and 22 to 30% in Thailand (New 1990). However, where natural food is available, prawns have been observed to grow when fed diets containing protein levels as low as 14% (Boonyaratpalin & New 1982; Bartlett &

Table 13.3 Specifications for freshwater prawn feeds under legislative control in Thailand. (Source: S. Thongrod, pers. comm., 1999.)

Type	Protein (%)	Lipid (%)	Ash (%)	Moisture (%)
Complete feeds				
Larvae (4–15 days)	>37	>5	<3	<10
Juveniles	>30	>4	<5	<12
Juveniles (5–12 g)	>25	>3	<6	<12
Large size prawns	>25	>3	<6	<12
Supplementary feed	>20	>3	<6	<12

Enkerlin 1983), and from 13 to 25% (Gomez Diaz *et al.* 1988). In Thailand, the composition of freshwater prawn feed and other aquafeeds has been placed under legislative control. The minimum and maximum specifications for the protein, lipid, ash and moisture contents of the feeds are presented in Table 13.3. The ingredient composition of a commercially manufactured experimental freshwater prawn grow-out feed is given in Table 13.4.

Compounds with possible chemoattractant and phagostimulant properties have been the subject of investigation because of their potential value in increasing the consumption of the food which is fed, and thereby reducing waste. Chemoattractive compounds incite movement toward the source of the compound whereas a phagostimulatory compound stimulates ingestion of food. Mendoza *et al.* (1997) evaluated the behavioural reaction to two biogenic amines (putrescine and cadaverine), and two sexual hormones (blue crab urine and freshwater prawn green gland extracts) relative to reference products known to be major attractants, such as squid extracts and a commercial product (Langobuds®). The results of a laboratory assay and feeding tray trials in ponds at commercial farms indicated that a 0.2% supplement of cadaverine was the best attractant when included in a basal 'unpalatable diet' containing a high level of soybean meal (30%). Interestingly, the blue crab urine and freshwater prawn green gland extracts attracted only males, suggesting that these substances might play a future role in effectively separating males for monosex culture, if such a management approach is deemed economically practical. Harpaz (1997) observed an increase in search behaviour and food consumption in juvenile *M. rosenbergii* when betaine, a known feeding attractant, was added to water after feeding. Growth (weight gain) of prawns exposed to the betaine increased by 17%. Harpaz *et al.* (1987) also identified the amino acids taurine, glycine, arginine, and trimethylamine, as having strong chemoattractant properties. Costa-Pierce & Laws (1985) also noted the chemoattractive properties of trimethy-

Table 13.4 Composition of a commercially manufactured (extruded) slow-sinking pelleted diet for pond grow-out of *Macrobrachium rosenbergii*. (Source: Producers Feed Company, Isola, Mississippi [W. Clay, pers. comm. 2000].)

Ingredient	Composition (%)
Soybean meal (48% crude protein)	39.00
Cottonseed meal (41% crude protein)	16.40
Meat/bone/blood meal (65% crude protein)	2.25
Menhaden fish meal (67% crude protein)	1.10
Wheat middlings	24.70
Whole maize	10.90
Catfish oil	4.40
Vitamin mix[a]	0.10
Mineral mix[a]	0.05
Dicalcium phosphate	1.10
Total	100.00
Analysed composition	
Protein (% DW basis)	38.7
Lipid (% DW basis)	6.6
Ash (% DW basis)	8.6
Moisture (%)	15.2

[a] The vitamin and mineral mixes are commercially manufactured and formulated to meet the reported requirements of channel catfish (NRC 1983), except for vitamin C.
DW = dry weight.

lamine. This compound has a faecal odour and the attraction may be partially attributed to the coprophagous nature of prawns.

13.3.2 Ingredient studies and the use of farm-made feeds

13.3.2.1 Ingredient studies

With the knowledge that freshwater prawns are omnivorous, it is understandable that, in addition to the more 'conventional' feedstuff ingredients, many less common raw materials have been reported to be satisfactory for grow-out feeding, either as supplementary feeds or as ingredients in formulated feeds. These include corn silage (Moore & Stanley 1982), fresh leaves (Harpaz & Schmalbach 1986), moist pressed brewers' grains (Kohler & Kreuger 1985), silkworm pupae with shrimp waste (Ravishankar & Keshavanath 1988), earthworms (Mossman *et al*. 1990 *apud* New 1995), beef liver (Heinen & Mensi 1991), beef liver and orange flesh, peeled sweet potatoes, frozen peeled bananas, butternut squash, yellow squash, and turnip greens and carrot tops (these two were found to enhance prawn pigmentation) as supplements to a commercial trout chow (Garces & Heinen 1993), dry sugar cane yeast, *Saccharum officinarum*, a product of alcohol production from sugar cane (Zimmermann & Cohen 1991), marine shrimp meal, fish meal and meat meal (Zimmermann *et al*. 1989), a legume and three types of grasses as inexpensive fibre sources (Zimmermann 1992a,b), distillers' dried grains with solubles (Tidwell *et al*. 1993), squid waste (Prasad *et al.* 1994), silkworm litter (Sivasankar & Ashoka 1997) and leucaena (Oliveira *et al.* 1998). The omnivory of freshwater prawns provides an opportunity of using locally available feedstuffs. Due to the comparatively low amounts available, and the unreliability in the supply of these feedstuffs, large companies are not interested in using them as ingredients in commercially manufactured feeds. However, use of locally available feedstuffs substantially improves the prospects for the sustainability of freshwater prawn farming (see Chapter 23).

13.3.2.2 Farm-made feeds

Farm-made feeds have been defined as 'feeds in pellet or other forms, consisting of one or more artificial and/or natural feedstuffs, produced for the exclusive use of a particular farming activity, not for commercial sale or profit' (New *et al.* 1993). Many, perhaps most, countries that are major producers of farmed freshwater prawns use farm-made feeds (Fig. 13.1). New & Csavas (1993b) reported that farm-made feeds were used in farming practices in India, Thailand and Vietnam, and in experimental work in Malaysia and Nepal. Lacroix *et al.* (1993) noted that 90% of Brazilian freshwater prawn farms were <3 ha and preferred to make their own feed. New & Csavas (1993a) estimated that about 41 000 t of freshwater prawn feeds were manufactured in Asia in 1990, an amount that was expected to exceed 112 000 t by 2000. Since the publication of that paper, statistics about the scale of freshwater prawn farming in China have become available (see Chapter 1). Farm-made aquafeeds are commonly used in China, and the quantity of feeds produced

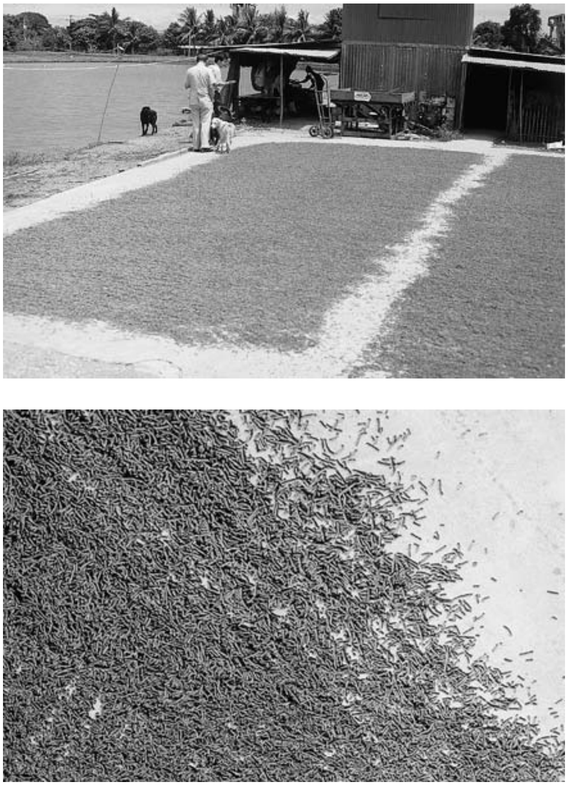

Fig. 13.1 Farm-made feed for *Macrobrachium rosenbergii* being sun-dried in Thailand

for prawns must have substantially exceeded the level of production forecasted for 2000 by New & Csavas (1993a).

The methods of producing farm-made feeds for prawns are described by New & Singholka (1985), New (1987), and by various authors in New *et al.* (1993). As discussed in section 13.3.2.1, a wide range of ingredients is available and suitable for inclusion. However, as pointed out by New & Csavas (1993b), the quality of many farm-made feeds can be significantly improved by better formulation that is based on improved knowledge about the analytical characteristics of locally available ingredients. In addition, better methods of feed processing and storage, and a better understanding of the role of natural food organisms are needed. The inherent risk in using unprocessed aquatic animal ingredients, particularly crustacean wastes, needs to be addressed. The extreme variability in the analytical and quality characteristics of locally available ingredients precludes recommendation of any single formula as most suitable for prawns. However, the variety of ingredients used in dietary formulations is best illustrated by the ingredient composition of farm-made feeds used on two farms in Thailand (Tables 13.5 and 13.6) and some experimental diets fed to prawns in Brazil, Indonesia, Israel and Thailand (Tables 13.7–13.10). Table 13.11 presents the formula of a low-cost supplementary prawn feed used in Bangladesh.

Table 13.5 Formulae of farm-made freshwater prawn feeds used on Thai farm 'A'. (Source: Boonyaratpalin & New, 1993.)

	Composition formula #1		Composition formula #2	
Ingredient	(kg)	(%)	(kg)	(%)
Trash fish	100.0	29.61	100.0	28.35
Soybean meal	40.0	11.84	40.0	11.34
Fish meal	20.0	5.92	10.0	2.84
Corn meal	80.0	23.70	80.0	22.68
Di-calcium phosphate	2.0	0.59	2.0	0.57
Oxytetracycline	0.2	0.06	–	–
Vitamin and mineral mix[a]	0.5	0.15	0.5	0.14
Vitamin C	–	–	0.2	0.06
Broken rice (boiled)[b]	30.0	8.88	30.0	8.51
Chicken layers' feed	50.0	14.81	60.0	17.01
Piglet feed	15.0	4.44	15.0	4.25
Shrimp shell meal	–	–	15.0	4.25
Totals (approximate)	337.7	100.00	352.7	100.00

[a] No details available.
[b] Weight before boiling.

13.4 Feeding strategies

Information on feeding strategies is contained in several other chapters of this book including Chap-

Table 13.6 Formula of farm-made freshwater prawn feed[a] used on Thai farm 'B'. (Source: Boonyaratpalin & New, 1993.)

		Composition	
Ingredient	Cost (US$/t)	(kg)	(%)
Trash fish	220	100	44.2
Chicken feed	240	60	26.6
Broken rice	168	30	13.3
Fish meal	720	20	8.8
Piglet concentrate[b]	427	15	6.6
Premix[c]	4400	1	0.5
Total[d]	480	226	100.0

[a] Lipid not less than 4%; protein not less than 25%; fibre not more than 8%.
[b] Composition unknown.
[c] Contains vitamins A, D, C, and E, and an unspecified antibiotic (oxytetracycline?). Available locally and specifically designed for *Macrobrachium*. Manufacturer suggests an inclusion rate of 0.5–1.0%.
[d] It was said that no water was added; trash fish provides sufficient moisture.

Table 13.7 Formulae of experimental feeds for freshwater prawns in Brazil. (Source: Zimmermann, 1988.)

	Composition (%)	
Ingredient	Feed #1	Feed #2
Shrimp meal	31.6	–
Fish meal	–	23.0
Soybean meal (44% crude protein)	34.4	32.6
Maize meal	14.2	17.5
Alfalfa meal	10.3	13.2
Fish oil	4.7	3.7
Di-calcium phosphate	3.1	4.9
Monosodium phosphate	0.7	4.1
Premix[a]	0.4	0.4
Iodised salt	0.5	0.5
Binder[a]	0.1	0.1
Totals	100.0	100.0

[a] No details available.

Table 13.8 Formulae of experimental feeds for freshwater prawns in Indonesia. (Source: Manik, 1976.)

	Composition (%)	
Ingredient	Feed #1	Feed #2
Fish meal	20.0	–
Shrimp head meal	–	30.0
Soybean meal	9.0	4.0
Rice bran	45.0	35.0
Coconut oil cake	20.0	20.0
Tapioca	5.0	9.0
Pfizer premix A[a]	1.0	1.0
Agar	–	1.0
Totals	100.0	100.0

[a] Details not available.

Table 13.9 Formulae of experimental feeds for freshwater prawns in Israel. (Source: Zimmermann, 1992a,b.)

	Composition (%)	
Ingredient	Feed #1	Feed #2
Soybean meal (44% crude protein)	22.4	20.7
Fish meal	20.0	20.0
Maize meal	18.6	6.5
Dried yeast	10.0	10.0
Wheat meal	10.0	10.0
Wheat bran	–	8.8
Grass meal (*Bracharia purpurescens*)	12.7	15.0
Di-calcium phosphate	3.8	3.4
Lime (calcite)	0.1	0.4
Fish oil	1.4	4.3
Premix[a]	0.5	0.4
Iodised salt	0.5	0.5
Totals	100.0	100.0

[a] No details available.

Table 13.10 Formulae of experimental feeds for freshwater prawns in Thailand. (Source: Boonyaratpalin & New, 1982.)

	Composition (%)	
Ingredient	Feed #1	Feed #2
Fish oil	3.0	3.0
Shrimp meal	25.0	10.0
Fish meal	10.0	4.0
Peanut meal	5.0	2.0
Soybean meal	5.0	2.0
Broken rice	25.5	39.0
Rice bran	25.5	39.0
Guar gum	1.0	1.0
Totals	100.0	100.0

Table 13.11 Formulae of low-cost supplementary freshwater prawn feed in Bangladesh. (Source: Gray, 1990.)

Ingredient	Composition (%)
Fish meal[a]	22.5
Fresh trash fish	10.0
Rice bran	20.0
Ground rice	17.5
Sesame cake	12.5
Fish oil	2.5
Sago	7.0
Cane molasses	6.5
Animal grade vitamin C[b]	0.5
Water	1.0
Total	100.0

[a] At least 50% protein.
[b] Optional.

ters 4 (broodstock), 5 and 6 (hatchery), 8 (nursery), and 10 (grow-out). Clearly, more investigations are needed to develop a better understanding of the relative value of fertilisation and supplemental diets and how their use is best co-ordinated with the biomass density of freshwater prawns in culture ponds. The best feed and feeding strategies are definitely influenced by the resident biomass (standing crop) in the pond. For example, a possible feeding strategy might be based on estimated biomass density and consist of the use of low protein diets initially, followed by low protein diets combined with a fertilisation routine, and finally the feeding of a higher protein, more nutritionally complete diet without fertilisation. D'Abramo & Sheen (1994) stated that no feeding of pelleted feed is required until the biomass density of pond populations has reached approximately 18 g/m^2. At this point the natural productivity (without fertilisation) can no longer sustain maximum growth rates and a feed is required either to enhance natural productivity and/or to serve as a direct source of nutrients. As the standing crop within a pond increases, feeding strategies that will ensure the satisfaction of nutrient requirements by a combination of formulated feed and natural food organisms need to be instituted.

13.5 Conclusions

The types of feed and feeding strategy that are employed in freshwater prawn pond culture are dictated by the stocking practice and the production goals. However, the expansion of aquaculture and the realisation of the importance of sustainability have led to an analysis of what constitutes sustainable aquaculture practices (Chapter 23). These practices appear to be rooted in a consciousness of the environmental and human dimensions. Accordingly, the most efficient and sustainable pond production practices probably lie in semi-intensive grow-out systems (Chapter 10) where resources are most efficiently managed, the risk is not high, and the level of interference is minimised. Pond production of *M. rosenbergii* is commonly characterised by semi-intensive systems. In the future, effective pond culture of freshwater prawns using these systems will probably follow a strategy that incorporates organic fertilisation of ponds during all stages of growth. This procedure will be designed to establish the best nutritional environment possible without sacrificing water quality. In later stages of growth, water-stable, formulated diets designed to increase feeding efficiency should be introduced. However, the required amounts of protein and lipid do not need to be included in the diet because any deficiencies in essential amino acids and fatty acids are likely to be compensated for by natural food organisms, as suggested by Tidwell *et al.* (1998).

In formulated grow-out diets, most of the dietary energy requirement can be derived from highly digestible sources of carbohydrate, thereby minimising the use of protein as an energy source. Complex starches such as cellulose and chitin may have nutritional value, suggesting that plant-derived and animal-derived feedstuffs may be equally effective. Use of regional feedstuffs that are available on a reliable basis is recommended, given they represent good nutritional quality, i.e. highly digestible with good nutrient profiles.

The successful development of a formulated larval diet that can serve as a complete or partial substitute for live foods will result in significant cost savings and introduce a greater degree of certainty in producing healthy PL. A formulated diet would allow the hatchery operator to exercise control over food size and nutrient composition of the food. Obtaining nutritional information about larvae is probably the greatest challenge for future research directed towards understanding the nutrition of freshwater prawns.

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14
Grow-out Systems – Water Quality and Soil Management

Claude Boyd and Sergio Zimmermann

Successful culture of freshwater prawns in ponds depends upon maintaining good water and soil quality. There are several books dedicated to general water and soil quality in ponds (Brune & Tomasso 1991; Boyd & Tucker 1992, 1998; Delincé 1992; Boyd 1995), but these give little information specific to freshwater prawn ponds. Water–soil relationships in ponds and their interactions with aquatic animal production are very complex. Water has many physical, chemical and biological characteristics, but only a few are normally important and even fewer can be effectively controlled in grow-out ponds for freshwater prawns.

Although there has been considerable attention to the quality of water used in *Macrobrachium rosenbergii* hatcheries (see Chapters 5 and 6), research specific to soil and water quality in freshwater prawn ponds has been minimal to date. This chapter therefore presents those aspects of the general 'state-of-the-art' concerning pond water and soil quality, and its management, which experience shows to be relevant to prawn farming, in addition to reviewing the specific literature that does exist on this aspect of prawn grow-out. Water quality in primary and secondary nurseries is covered in Chapter 8.

14.1 Water quality: impact and control

Physical, chemical and biological aspects of water influence the ability of prawns to perform physiological functions, including growth, disease resistance, reproduction, and tolerance to extreme temperatures. Aquaculture species are in more intimate contact with their own waste than are terrestrial species, because the water in which they live also is, necessarily, self-contaminated (Tomasso & Brune 1991). Schreck & Li (1991) pointed out that semi-intensive aquaculture ponds, such as those used for freshwater prawns, are extremely complex ecosystems. The consequences of pond management to improve soil and water quality are site specific, and procedures that are successful at one site may fail at another place (Boyd 1990). Pond management must be customised for each individual pond.

There are three basic types of water quality problems in ponds (Boyd 1990). The first involves undesirable characteristics in the water supply. Problems with the water supply usually can be minimised by wise site selection or mitigated by special design, construction, or management techniques. For example, pollutants may enter ponds from the surroundings as the result of multiple uses of watersheds, but this problem can be mitigated where it is possible to divert polluted runoff from ponds. However, when a river that supplies water to aquacultural ponds is polluted by a variety of municipal, industrial, and agricultural effluents, there may be no effective way of dealing with the problem. The second type of problem concerns events that develop in ponds as a result of the culture system. High natural productivity is usually a result of feeding to enhance prawn production, and it causes a high abundance of phytoplankton, a low concentration of dissolved oxygen (DO_2), thermal and chemical stratification, high pH, and excessive concentrations of metabolites such as ammonia, carbon dioxide, and nitrite. Farm managers therefore need to realise that, regardless of management inputs, production has economically imposed limits. The third aspect of water quality in aquaculture which may become a problem relates to the influence of production practices on the outside environment. The most important consideration probably is the possible eutrophication of natural waters caused by pond effluent discharge.

There are several procedures that can be used to maintain or improve water quality (Boyd 1990). The most effective are: proper site selection, sound design and construction practices (see Chapter 9); liming and fertilisation; regulation of feeding rates (see Chapters 10 and 13); mechanical aeration; water exchange; bottom soil treatment; and the protection of watersheds. Feeding and water quality are particularly closely related, for good feed conversion efficiency depends upon maintaining adequate water quality in ponds. Also, as feeding rates increase, water quality in ponds tends to deteriorate.

14.1.1 Dissolved oxygen

Respiration by prawns requires oxygen which is acquired from the water by diffusion across the gills. Respiratory and circulatory systems of prawns have evolved to function effectively over a range of DO_2 concentrations, from above air saturation down to a concentration at which oxygen-demanding activities become constrained. Prawn metabolism adapts to limiting oxygen concentrations by reducing non-obligatory activities such as swimming, digesting food, growing, and processing feed.

The amount of oxygen required by aquatic animals is variable, and depends primarily upon size, food intake, activity, water temperature, and DO_2 concentration. Several factors may contribute to increased oxygen demand for a limited period, such as higher temperatures, stress, high ammonia concentrations in the culture water, swimming, or an increase in the digestion or metabolism of feeds (Neill & Bryan 1991).

When DO_2 concentrations gradually decline, but other water quality parameters remain stable, prawns can maintain a relatively constant oxygen absorption rate by increasing ventilation rate and perfusion. When the concentration of DO_2 falls below 1 mg/L for *M. rosenbergii*, those regulatory measures become exhausted with serious physiological effects leading to suffocation. Most aquatic organisms present a very limited capacity of anaerobic metabolism, and they are conditioned for maximum activity or active metabolism at oxygen concentrations of 3 to 7 mg/L (Smith 1982). Rogers & Fast (1988) reported that prawns became stressed at DO_2 levels below 2 p.p.m.

As a basic rule, low DO_2 concentrations in prawn ponds may be expected to occur if daily feeding rates exceed 25 to 35 kg/ha in prawn ponds without mechanical aeration or water exchange. At these feeding rates, prawn production is unlikely to exceed 1000 to 2000 kg/ha/yr. When water exchange and aeration are used, feeding rates may be increased, and production can be increased to 2000 to 5000 kg/ha/yr. Although aeration may provide higher DO_2 concentrations, increased feeding rates in aerated ponds usually cause concentrations of total ammonia nitrogen (NH_3–N) to rise. Higher feeding rates also tend to increase the quantity of organic matter in pond soils as a result of higher feeding rates. This can cause lower DO_2 concentrations at the bottom of the pond, as well as the appearance of reduced microbial metabolites such as nitrite, ferrous iron, hydrogen sulphide, and methane. These reduced substances diffuse into water and are toxic to prawns.

14.1.2 Temperature

Freshwater prawns are poikilothermic or 'cold blooded'. Generally, the metabolic demand for oxygen in aquatic animals doubles or triples with every 10°C increase within the range of temperature that the animal can tolerate. However, the physiological capacity to supply this oxygen rises sigmoidally to a maximum at a species-specific optimum temperature, and then decreases with further temperature increase (Neill & Bryan 1991).

The optimum metabolic temperature range for *M. rosenbergii* is between 26 and 32°C. Deficiencies in DO_2 concentrations may limit metabolism even within the optimum temperature range. Other environmental stressors can increase the obligatory demand for oxygen, reduce the physiological capacity to supply it, decrease the metabolic scope at all temperatures, and shift the optimum temperature for maximising the surplus metabolic capacity which, in combination with adequate nutrition, leads to growth. Rogers & Fast (1988) reported that prawns were stressed by temperatures below 22°C. According to Zimmermann (1998) freshwater prawns cease to grow and may not survive for long periods when water temperatures are below 19°C or above 34°C. The tolerance time to extreme temperature depends basically on prawn age and size. Postlarvae (PL) are more tolerant of lower temperatures when compared to juveniles or adults. At temperatures below 12°C or above 42°C, prawns rapidly die. Neill & Bryan (1991) postulated that the logarithm of survival time upon abrupt transfer to lethally warm or cold water is linearly related to temperature. For example, if an aquatic organism resists heat death at 32°C for 1000 min and at 34°C for 100 min, it will die at 36°C in only 10 min. Farmanfarmaian & Moore (1978) found that freshwater prawn growth doubled for every 5°C increase within the range 20 to 30°C, with no appreciable change in feed conversion ratio (FCR).

Freshwater prawns present characteristic physiological responses to physico-chemical factors. This pattern of behaviour allows prawns, at least at lower culture densities, to move to better sites in the pond where environmental conditions are tolerable. Under the semi-intensive culture system, this search for a better environment (enviro-regulation) is limited, so freshwater prawns must use physiological mechanisms of adaptation or acclimation. According to Neill & Bryan (1991), in dealing with temporal variation, aquatic organisms must rely on physiological mechanisms of adaptation which are termed 'acclimation' (responses to change in individual environmental factors) or 'acclimatisation' (responses to change in the entire environmental complex). It takes *M. rosenbergii* from several hours to several weeks to physiologically adjust to changes in temperature, DO_2, salinity, and ammonia. Temperature acclimation occurs at a rate that increases with ambient temperature; so upward acclimation is faster than downward acclimation over the same range of temperature. For example, if acclimation from 20 to 30°C is 90% complete in 2 days, the reverse process could take 2 weeks; and acclimation to low oxygen may require from 1 week to 1 month.

14.1.3 Other water quality parameters

Apart from temperature and DO_2, several other water quality parameters are directly involved with *M. rosenbergii* metabolism including pH and ammonia, nitrite, nitrate, calcium, magnesium, potassium, phosphorus, iron, sulphate, and sodium concentrations. Table 14.1 lists the actual range of water quality parameters found in 135 water samples from 25 freshwater prawn ponds on five farms in Southern and Northeastern Brazil being used for semi-intensive culture. Though this data

Table 14.1 Concentrations of major water quality variables found in 25 freshwater prawn ponds in two regions of Brazil. (Source: Núcleo de Pesquisas em Aquacultura e Hidrologia da Universidade Luterana do Brasil (ULBRA), Canoas, Rio Grande do Sul – unpublished data, 1998.)

Parameters	Unit	Southern region	Northeastern region
pH		5.5–7.6	6.9–8.3
Ammonia nitrogen (NH_3–N)	mg/L	0.1–0.5	0.1–0.3
Nitrite nitrogen (NO_2–N)	mg/L	0.1–1.7	0.1–0.7
Alkalinity ($CaCO_3$)	mg/L	7–101	10–102
Hardness ($CaCO_3$)	mg/L	10–45	12–75
Calcium (Ca)	mg/L	0.02–18.6	0.01–1.2
Magnesium (Mg)	mg/L	0.01–6.8	0.01–1.5
Total phosphorus (P)	mg/L	0.01–4.4	0.003–0.34
Potassium (K)	mg/L	0.01–4.9	0.06–1.6
Sodium (Na)	mg/L	0.26–10.0	7.7–30.0
Sulphate (SO_4)	mg/L	0.25–12.1	0.1–26.0
Boron (B)	mg/L	0.04–0.74	0.1–0.2
Copper (Cu)	mg/L	0.02–0.1	0.02–0.13
Iron (Fe)	mg/L	0.02–6.0	0.02–0.21
Manganese (Mn)	mg/L	0.01–0.10	0.01–0.31
Zinc (Zn)	mg/L	0.01–0.08	0.01–0.20

confirms that prawn culture is feasible in waters having these characteristics, little or no research information is available on optimum water quality for these parameters.

While information on other water quality characteristics is sparse, there has been some work on calcium. Freshwater prawns, like most crustaceans, require high calcium concentrations for the enzymatic processes involved in moulting, and there is also a relationship between magnesium and neural-muscular energy transmission. New & Singholka (1985) postulated that calcium hardness concentrations of 40 to 100 mg/L $CaCO_3$ are optimum for growth of *M. rosenbergii*, while Vasquez *et al*. (1989) found 20 to 200 mg/L to be optimal. Very high water hardness often results in encrustation with *Bryozoa* sp. and *Epistylis* sp., which retard growth rate. However, Bartlett & Enkerlin (1983) postulated that high calcium levels may not be detrimental unless combined with high carbonate levels. Successful prawn rearing was reported by these authors in areas having water supplies with 940 to 1060 mg/L of calcium where the carbonate content was nil but sulphate and chloride levels were also high. Zimmermann *et al.* (1994) have demonstrated the interactions between calcium concentrations in pond water and in prawn feed (see Chapter 13). Although it would be cheaper to correct calcium deficiencies by increasing the calcium content of feed, manufacturing site-specific prawn feeds is not practical. Ponds supplied by low calcium water need to be treated with calcium compounds to increase dissolved calcium concentrations.

Most freshwater prawn farms utilise surface freshwater sources but several research and pilot-scale attempts have been made to culture *M. rosenbergii* in geothermal waters, which often have an unsuitable ionic composition, and were recorded by New (1990). One of these early ventures, in New Zealand, has been able to utilise the waste heat from a geothermal power station (see Chapter 17) by employing heat exchangers to elevate the temperature of the river water used in its ponds, thus avoiding any problems caused by the ionic composition of the geothermal water.

According to Singh (1980) isosmotic conditions are not required for optimal growth. Smith *et al.* (1982) indicated that salinities of up to 10 p.p.t. give results as good as freshwater, while salinities between 12 and 25 p.p.t. were used experimentally by Popper & Davidson (1982). Stern *et al*. (1987) reported that *M. rosenbergii* kept for long periods in freshwater, and in 15 and 24 p.p.t. brackishwater of varying ionic composition (three different brackishwater sources), were able to regulate and maintain their haemolymph osmolality and ionic composition (sodium, chloride, potassium, calcium and magnesium).

Strauss *et al.* (1991) performed tolerance tests with non-ionised ammonia at high pH with *M. rosenbergii* PL and juveniles and suggested that PL should not be exposed to a pH >9.0 or to >1.0 mg/L NH_3–N in the pH range 8.5 to 9.0. These authors also suggested that juveniles should not be exposed to pH >9.5, or to NH_3–N levels of >0.5 mg/L at pH 9.5, >1 mg/L at pH 9.0, or >2 mg/L at pH 8.5. Strauss *et al*. (1991) concluded that it was desirable to stock PL in ponds as early in the morning as possible, when the pH levels are lowest, or immediately after pond filling and before a dense phytoplankton bloom develops. Stocking juveniles instead of PL, since the former are more tolerant of high pH and ammonia, was also recommended by these authors. Chen & Lee (1997) found that the 96 h LC_{50} (96-hour lethal concentration) of nitrite nitrogen was 8.49, 11.21, and 12.87 mg/L at chloride levels of 15, 24, and 24 mg/L, respectively.

14.1.4 Recommended water characteristics

Zimmermann (1998) compiled data from many publications to create a series of 'ideal' ranges for a limited number of water quality parameters for the grow-out phase of *M. rosenbergii* (Table 14.2). It should be noted that the 'ideal' water hardness level listed in Table 14.2 is based only on the

Table 14.2 Ideal ranges for water quality variables for the grow-out phase of *Macrobrachium rosenbergii*. (Source: modified from Zimmermann, 1998.)

Parameter	Ideal range
Temperature	25–32°C
Transparency	25–40 cm
Alkalinity ($CaCO_3$)	20–60 mg/L
Hardness ($CaCO_3$)	30–150 mg/L
Non-ionised ammonia	0.1–0.3 mg/L
Dissolved oxygen	3–7 mg/L
pH	7–8.5

hardness caused by calcium. According to Brown (1991), the hardness caused by magnesium may also be important to prawns.

The optimum ranges for most water quality variables in the environmental study of freshwater prawn ponds are unavailable. However, ranges of suitable water and soil characteristics for aquaculture in Southern Brazil (including freshwater prawn culture) have been drawn up (Table 14.3) and it is suggested that this table should be used to provide guidelines for application elsewhere.

14.1.5 Control of water quality

The maximum prawn biomass that a pond can support depends on water quality and the available food. Stocking more animals per area does not necessarily result in higher production of prawns of commercial size. However, pond productivity can be significantly increased if more food (either natural or supplementary) is available, and if water quality is maintained within an optimum range. The use of supplementary feeds is discussed in Chapter 13. The best way of increasing the natural food available in a pond is through liming and fertilisation.

14.1.5.1 Liming

Some waters may have total alkalinity and total hardness concentrations less than optimum for *M. rosenbergii*, and liming materials should be applied over pond surfaces to increase total alkalinity to 40 to 50 mg/L. There are several types of liming materials, the most common being agricultural limestone, burnt lime, and hydrated lime. Agricultural limestone is made by finely pulverising limestone. Limestone consists of calcium carbonate or a mixture of calcium and magnesium carbonates. Limestone may be burned in a kiln to drive off carbon dioxide and yield a product called burnt lime which consists of calcium oxide or a mixture of calcium and magnesium oxides. Hydrated lime is prepared by adding water to burnt lime to convert the oxides to hydroxides. The properties of liming materials are fully discussed by Boyd & Masuda (1994) who emphasised that agricultural limestone is the material of choice for liming aquaculture ponds. Normally, burnt lime or hydrated lime should not be applied to pond water.

Agricultural limestone will dissolve in pond waters when total alkalinity is less than 60 mg/L (Boyd 1990). However, the bicarbonate and carbonate resulting from the dissolution of agricultural limestone will react with the acidic components of the pond soil, and unless enough limestone is applied to neutralise bottom soil acidity, liming will have little lasting effect on total alkalinity. Therefore, the liming rate for a pond should be based on the lime requirement of the soil. The acidity of soil is associated with the fine, clay-sized particles, so lime requirement increases as soil pH decreases and soil texture becomes finer. Data provided by Boyd & Tucker (1998) may be used to obtain lime requirements for pond soils based on soil pH and rough estimates of soil texture (Table 14.4). The soil pH should be measured in a 1 : 1 mixture of dry pulverised soil and distilled water. Pillai & Boyd (1985) developed a chemical procedure for determining lime requirement of pond soils, but this method requires laboratory soil analysis. As an alternative to measuring lime requirement, aquaculturists may apply lime to ponds at rates similar to those used on agricultural soils in the surrounding area, but application rates normally should be at least 500 kg/ha; usually 1000 kg/ha is required for a good response (Boyd 1990).

When applying agricultural limestone to prawn pond water, it should be spread uniformly over the pond surface in the dormant season before pond fertilisation is initiated. When phosphate fertiliser and agricultural limestone are applied within the same week, much of the phosphate added to the water by fertilisation may be lost through precipitation as calcium phosphate (Boyd & Tucker 1998). The residual effect of liming depends upon the residence time of water in ponds. Ponds that have considerable flow-through, or that are drained annually, may need to be limed every year. The best way to determine if a pond needs to be treated with agricultural limestone is to measure total alkalinity. In *M. rosenbergii* culture, agricultural limestone should be applied if waters contain less than 30 to 40 mg/L total alkalinity. Waters containing over 60 mg/L total alkalinity probably should not be limed, because the limestone will not dissolve in them unless there is an abundance of carbon dioxide.

There are instances where waters exhibit a high level of total alkalinity but a low total hardness.

Table 14.3 Ranges of water and soil quality variables recommended for aquatic life in Southern Brazil. (Source: modified from NRS/SBCS, 1995. This information is based upon local environmental requirements, flooded rice technology and aquaculture literature.)

	Water		Soil	
Parameter	Range	Unit	Range	Unit
pH	7.0–8.0		>4.5	
Total ammonia nitrogen	<0.5	mg/L		
Nitrite nitrogen (NO_2–N)	<1.0	mg/L		
Nitrate nitrogen (NO_3–N)	<10.0	mg/L		
Alkalinity ($CaCO_3$)	40.0–50.0	mg/L		
Hardness ($CaCO_3$)	20.0–40.0	mg/L		
Calcium (Ca)	12.0–25.0	mg/L	2.5–4.0	Meq/100 g
Magnesium (Mg)	<20.0	mg/L	0.5–1.0	Meq/100 g
Ca + Mg	<100.0	mg/L	2.5–5.0	Meq/100 g
Potassium (K)	300–400	mg/L	20–120	p.p.m.
Orthophosphate (P)	<0.3	mg/L		
Total phosphorus (P)	<0.025	mg/L		
Sodium (Na)	<30.0	mg/L	<1000	p.p.m.
Residual chlorine	<0.01	mg/L		
Chloride (Cl)	<250	mg/L		
Fluoride (F)	<1.4	mg/L		
Sulphate (SO_4)	<250	mg/L	2.0–5.0	p.p.m.
Hydrogen sulphide (H_2S)	<0.002	mg/L		
Specific conductance	100–200	µS/cm		
Turbidity	<40	unit		
Total dissolved solids	<500	mg/L		
Faecal coliforms	200–1000	NMP/100 ml		
Total coliforms	1000–5000	NMP/100 ml		
Oil and grease	Absence	–	Absence	–
Pesticides	Absence	–	Absence	–
Aluminium (Al)	<0.1	mg/L		
Arsenic (As)	<0.05	mg/L		
Barium (Ba)	<1.0	mg/L		
Beryllium (Be)	<0.1	mg/L		
Boron (B)	<0.75	mg/L	0.1–0.3	p.p.m.
Cadmium (Cd)	<0.001	mg/L		
Lead (Pb)	<0.03	mg/L		
Cyanide (CN)	<0.01	mg/L		
Cobalt (Co)	<0.2	mg/L		
Copper (Cu)	<0.02	mg/L	0.15–0.40	p.p.m.
Chromium (Cr)	<0.05	mg/L		
Iron (Fe)	0.3–1.0	mg/L	<17.0	p.p.m.
Manganese (Mn)	<0.1	mg/L		
Mercury (Hg)	<0.002	mg/L		
Nickel (Ni)	<0.025	mg/L		
Silver (Ag)	<0.01	mg/L		
Total uranium (U)	<0.02	mg/L		
Vanadium (V)	<0.1	mg/L		
Zinc (Zn)	<0.18	mg/L	0.20–0.50	p.p.m.

Liming will not increase total hardness in such waters, but total hardness can be increased by applying calcium sulphate (gypsum). The application rate needs to be about 2 mg/L gypsum for each 1 mg/L increase in total hardness (Wu & Boyd 1990). For example, if the total hardness is 15 mg/L, and it is desired to have a total hardness of 50 mg/L, 70 mg/L of gypsum should be applied. This is equal

Table 14.4 Lime requirements of bottom muds based on pH and texture of mud. (Source: Boyd & Tucker, 1998.)

	Lime requirement (kg/ha as $CaCO_3$)		
Mud pH	Heavy loams or clays	Sandy loam	Sand
<4.0	14320	7160	4475
4.0–4.5	10740	5370	4475
4.6–5.0	8950	4475	3580
5.1–5.5	5370	3580	1790
5.6–6.0	3580	1790	895
6.1–6.5	1790	1790	0
>6.5	0	0	0

to 70 g/m^3 of gypsum or 700 kg of gypsum in a 1 ha pond with a water depth of 1 m.

14.1.5.2 Mineral fertilisation

Mineral fertilisers are applied to pond water to increase concentrations of nutrients and stimulate phytoplankton productivity. Greater phytoplankton productivity has three basic benefits: it increases the base of the food chain to provide more natural food for prawns, it creates turbidity in the water to prevent underwater weed growth, and the turbidity shelters the prawns from bird predation. In freshwaters, nitrogen and phosphorus are normally the limiting mineral nutrients for phytoplankton growth, so general fertilisation programmes are based on these two nutrients (Boyd & Tucker 1998). The best ratio of $N:P_2O_5$ in freshwater ponds appears to be 1:3 or 1:4. Di-ammonium phosphate (18% N and 48% P_2O_5) or mono-ammonium phosphate (11% N and 48% P_2O_5) are excellent pond fertilisers, but the desired ratio of nitrogen and phosphorus can be obtained by mixing together various other fertiliser source materials. Experiments on pond fertilisation (Boyd & Tucker 1998) revealed that applications of fertilisers which provide 4 to 8 kg P_2O_5/ha are sufficient to promote the growth of phytoplankton. However, applications usually need to be made at 2- to 4-week intervals to sustain a phytoplankton bloom in waters where feed inputs are low.

Granular fertilisers settle quickly before dissolving on the pond bottom (Boyd 1981). Soil quickly adsorbs phosphate and binds it tightly. It is preferable that fertilisers should be applied in a manner that allows them to dissolve before they contact bottom soil. One alternative is to use liquid fertiliser; an excellent choice is an ammonium polyphosphate (10% N and 34% P_2O_5) liquid fertiliser. This fertiliser has a density of 1.4, so it must be diluted with water and splashed over the pond surface to prevent it from sinking to the bottom. Another alternative is to use granular fertilisers but place them in a tank of pond water first, mixing them to provide a slurry to splash over the pond surface. It is also effective to apply granular fertilisers on underwater platforms or in porous bags suspended in the water, so that they can dissolve within the water column and away from the bottom soil. Recently, in the USA, several companies have been supplying a finely pulverised fertiliser for ponds. This material is so fine that it will dissolve almost instantly, and it may be broadcast directly over pond surfaces (Rushton & Boyd 1995).

In ponds where prawns are fed (which is the norm), considerable quantities of nutrients reach the water from feed wastes. Care must therefore be taken to prevent over-fertilisation and excessive phytoplankton blooms which may lead to low DO_2 concentrations. In ponds where turbidity results primarily from plankton, Secchi disks may be used as a guide to pond fertilisation. The best range in Secchi disk visibility is from 25 to 40 cm. Secchi disk visibility may be checked frequently, and when it is 25 cm or less, fertiliser should not be applied. The fertiliser dose also can be adjusted for Secchi disk visibility. For example, if the Secchi disk visibility is 40 cm or greater, the entire dose containing 4 to 8 kg P_2O_5/ha should be applied, but if the Secchi disk visibility is 30 cm, the dose should be reduced proportionally.

14.1.5.3 Organic fertilisation

Animal manures and other organic materials are often used as fertilisers in aquaculture ponds. Organic matter may provide food for zooplankton and other aquatic food organisms, and it decomposes to release nitrogen, phosphorus, and other nutrients into the water and stimulates phytoplankton growth. Manures can be just as effective as mineral fertilisers in stimulating the productivity of ponds (Olah *et al.* 1986), but animal manures in particular have several disadvantages for use in aquaculture. They have a variable composition, their nitrogen and phosphorus content is low, large amounts must be applied, they have an oxygen demand, their use results in organic residues on the pond bottom, detritus from manures provides a starting point for growth of filamentous algae, they have high concentrations of heavy metals, and they may be contaminated with antibiotics (Boyd & Tucker 1998). Animal manures should normally be discouraged for use in prawn ponds and mineral fertilisers favoured. If the aquaculturist really wants to use organic fertilisers, plant meals such as soybean meal, rice bran, or other products of more consistent composition and higher quality than animal manures should be used. Application rates for such materials should not exceed 20 to 30 kg/ha/day, and they should be broadcast over the pond surface.

14.1.5.4 Mechanical aeration

Aerators are mechanical devices which increase the rate at which oxygen enters water and utilise two basic techniques: (1) water is splashed into the air or (2) bubbles of air are released into the water. Hence, we have 'splasher' and 'bubbler' aerators.

Types of splasher aerators include vertical pump, pump-sprayer, and paddlewheel aerators. Vertical pump aerators consist of a motor with an impeller (propeller) attached to its shaft. The motor is suspended below a float with a centre opening and the impeller jets water into the air. Pump-sprayer aerators employ a centrifugal pump to spray water at high velocity through holes in a manifold and into the air. These types of aerators are not widely used. Paddlewheel aerators splash water into the air as the paddlewheels rotate. The small, electric paddlewheel aerator known as the 'Taiwan-style' aerator is often used in aquaculture. Much larger and more efficient electric paddlewheel aerators (Fig. 14.1) are used in channel catfish farming in the USA. Tractor-powered paddlewheel aerators can be used to supplement smaller aerators during low DO_2 crises or in ponds without an electrical supply. Paddlewheel aerators are probably used more widely in prawn farming than all other types of aerators combined.

Bubbler aerators include diffused-air systems and propeller-aspirator-pumps. In a diffused-air system an air blower is employed to deliver air through an air line, and the air is released through air diffusers located on the pond bottom or suspended in the water. The propeller-aspirator-pump aerator has a high velocity, uncased impeller at the end of a hollow shaft and housing. In operation, air flows down the shaft by the venturi principle and is released through a diffuser into the water as fine bubbles.

Boyd & Ahmad (1987) evaluated more than 30 types of aerators for aquaculture. The oxygen transfer efficiencies of aerators in kilograms of oxygen transferred per kilowatt-hour of power applied to aerator shafts for the basic types of aerators is summarised in Table 14.5. The most common use of aeration in aquaculture is probably to prevent stress and mortality when occasional oxygen depletions occur. This type of aeration is commonly called emergency aeration and is a proven management

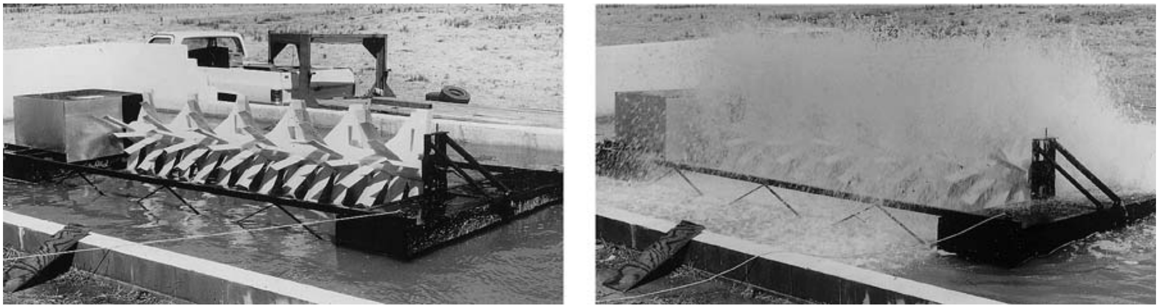

Fig. 14.1 Large electric paddlewheel aerator

Table 14.5 Oxygen transfer efficiencies of basic types of aerator. (Source: Boyd, 1990.)

Type of aerator	Average oxygen transfer efficiency (kg O_2/kW·hr)
Paddlewheel	2.13
Propeller-aspirator-pumps	1.58
Vertical pumps	1.28
Pump sprayers	1.28
Diffused air systems	0.97

tool. Farmers monitor DO_2 concentrations and pond conditions. When they expect the DO_2 concentration to fall below 2 to 3 mg/L, aeration is initiated and continued until there is no longer any danger of a DO_2 depletion. Emergency aeration is seldom necessary on more than a few nights per year, and then it is normally only needed between midnight and dawn, during prolonged periods of cloudy weather, or after plankton die-offs.

Aeration is usually required in crustacean ponds where feeding rates exceed 25 to 35 kg/ha/day (Boyd & Tucker 1998). It is needed more at night than in daytime, because photosynthesis usually maintains high concentrations of oxygen during the day. However, crustaceans live on the pond bottom, and mechanical aeration to circulate pond water continually replenishes the supply of oxygenated water at the pond bottom. Thus, daytime aeration of heavily stocked *M. rosenbergii* ponds is probably desirable (see Chapter 10).

It is difficult to select an ideal amount of aeration for aquaculture ponds because many variables influence DO_2 concentrations. However, Boyd (1997) provided calculations which suggest that each horsepower of aeration by a standard pond aerator will allow an increase in production of the cultured species of about 400 to 500 kg/ha above that possible without aeration.

14.2 Pond soil and sediment management

14.2.1 Soil nutrients and soil–water exchange

Pond soils consist of mineral particles (sand, silt, and clay) and organic matter particles that are intimately mixed. The fine particles of soil (clay and organic humus) are negatively charged and attract positively charged cations. Thus, the bottom soil acts as a cation exchange resin and has a capacity both to hold cations and to exchange cations with the water. Acidic soils also may contain minerals such as iron and aluminium hydroxides and oxides which can precipitate phosphorus as highly insoluble iron and aluminium phosphates or adsorb phosphate directly. In neutral or alkaline soils, phosphate is precipitated as highly insoluble calcium phosphates. The acidity of soils in freshwater ponds is usually related to the proportion of the cation exchange sites occupied by aluminium ions. Soils with high proportions of exchangeable aluminium are acidic. Neutral and basic soils have a small proportion or no exchangeable aluminium and may contain free calcium carbonate and gypsum. The organic matter in pond soils includes the remains of dead pond organisms, uneaten feed, faeces, and organic materials applied as fertilisers. This material ranges in size from detritus to simple, dissolved organic compounds, but much is in the form of humus. Further discussion of pond soil chemical composition may be found in Boyd (1995).

When water is applied to ponds, an equilibrium will be established between concentrations of substances in the soil and in the water. Assuming that aerobic conditions persist at the soil–water interface, the soil will tend to be a sink for phosphorus, and equilibrium phosphate concentrations in the water will be 0.1 mg/L or less (Masuda & Boyd 1994). Some ammonium may be adsorbed on cation exchange sites in bottom soil, but the largest influence of soil on nitrogen dynamics in pond water is the conversion of nitrate to nitrogen gas in the anaerobic soil beneath the soil–water interface (Hargreaves 1997). Organic matter decomposition releases carbon dioxide, ammonia, and other nutrients into the pond water. In acidic soils, alkalinity will be lost from water when it neutralises acidity in soils, but in neutral to alkaline soils, dissolution of calcium and magnesium compounds in pond soils may increase the total alkalinity and total hardness of pond water. If the soil–water interface becomes anaerobic, reduced and potentially toxic substances may enter the pond water.

14.2.2 Organic matter, respiration, and oxidation–reduction

The decomposition of organic matter in pond soils is the most critical soil process affecting production.

The organic matter may be decomposed either aerobically or anaerobically (Kristensen *et al.* 1995). In aerobic decomposition, the end products of decomposition are water, carbon dioxide, and mineral nutrients such as ammonia, phosphate, and sulphate, while in anaerobic decomposition, potentially toxic compounds such as hydrogen sulphide, nitrite, and certain organic compounds are formed. Water can circulate freely in the pond water column, but it can only move slowly by infiltration within the pores of pond soil. The rate that oxygen can enter the soil depends upon the rate of infiltration and diffusion of oxygen molecules through the water in the pore space. The microbial demand for oxygen in pond soils is high (Schroeder 1987), so aerobic conditions cannot be maintained for more than a few millimetres into the soil. When oxygen concentration becomes low, the redox potential declines (the soil becomes more reduced). The source of the reducing power (hydrogen ions) is the microbial degradation of organic matter. The more organic matter in the soil, the greater the potential for anaerobic conditions and low redox potential. When the redox potential is low, reduced and potentially toxic microbial metabolites accumulate in the pore water. However, as long as the soil–water interface remains aerobic (high redox potential), the reduced substances are blocked by reoxidation from entering the pond water. Thus, one of the objectives of pond soil management is to maintain aerobic conditions at the soil–water interface.

It is not necessary to measure the redox potential in soil to determine if conditions are oxidising (aerobic) or reducing (anaerobic); simple observation is sufficient. Oxidised soil has a much lighter colour than reduced soil. For example, the oxidised surface layer of soil in a pond is brown while the underlying reduced layer is black. This is the natural situation, and production problems will not result from the reduced sub-layer. However, when the black colour rises to the soil–water interface, reduced substances may enter the water and be toxic to the culture species.

The major factors affecting the decomposition of organic matter are moisture content, DO_2 concentration, pH, temperature, and the composition of the organic matter. Waterlogged soils are poorly oxygenated, and decomposition tends to occur by anaerobic processes at depths of a few millimetres below the soil–water interface. When pond bottoms are dried, air containing oxygen enters the pore spaces and cracks the soil to accelerate aerobic decomposition and oxidation of reduced compounds. However, if the soil becomes too dry, decomposition slows because of lack of moisture (Boyd & Pippopinyo 1994). Microbial decomposition occurs most rapidly at pH values between 7.5 and 8.5. Low pH favours slow decomposition and accumulation of organic matter (Boyd & Pippopinyo 1994). The decomposition of organic matter increases with increasing temperature within the temperature range found in aquaculture ponds. Organic matter with a narrow C:N ratio and containing a high proportion of non-cell wall material decomposes much faster than fibrous organic matter with a wide C:N ratio (Alexander 1961). In general, the types of organic matter deposited on the bottoms of aquaculture ponds readily decompose.

14.2.3 Pond sediments

When ponds are initially constructed, the surface soil from the pond bottom area is normally removed and used for the construction of pond embankments. The pond bottom of a newly constructed pond usually consists of a mineral soil with a low concentration of organic matter and is usually compacted to reduce infiltration, so it is smooth and hard. Sediment begins to form in pond bottoms once they are filled with water and aquaculture activities initiated. There are several sources of sediment, which include soil particles entering with the water supply, the erosion of pond bottoms and above-water portions of embankments, the remains of dead pond organisms, prawn faeces, and organic materials applied to ponds as fertilisers. The finer particles of clay and organic matter tend to migrate to the deeper water areas of ponds, and there is a general pattern of erosion from shallow areas and deposition in deeper layers. Distinct soil profiles quickly develop in the deeper areas of ponds (Munsiri *et al.* 1995). There is usually a flocculent layer high in water content and organic sediment just above the soil, a surface soil layer that tends to be well mixed and relatively high in organic matter, a layer of unmixed bulk sediment relatively high in organic matter, a transition layer, and finally the undisturbed and original pond bottom. These layers or horizons were named the F, S, M, T, and P horizons, respectively (Munsiri *et al*. 1995).

The organic matter contents of tropical aquaculture pond soils are usually not greater than 6 to 8% (3 to 4% organic carbon) even in the S horizon, but the solids in the flocculent layer (F horizon) above the S horizon are about 50% organic matter. The organic matter in the S and M horizons is partially decomposed and similar to humus in terrestrial soil. The most reactive organic matter is in the flocculent layer and the surface of the S horizon. In prawn ponds with high feeding rates and inadequate aeration, accumulation of organic matter in the F horizon and at the surface of the S horizon is likely to lead to anaerobic conditions.

Sometimes pond water supplies have heavy loads of suspended soil particles. When introduced into ponds, the soil particles quickly settle to the pond bottom and produce an undesirable layer of soft sediment. Pond volume is also lost through sediment accumulation.

14.2.4 Pond bottom management

14.2.4.1 Soil evaluation

The two most important variables for consideration in pond soil management are soil pH and organic carbon. Both of these variables can be easily measured. The best time to obtain the soil sample is soon after the pond has been drained, but before any soil treatments have been applied. Soil samples should be collected from several places in the pond bottom. It is adequate to take 10 to 12 random samples of the upper 5 cm layer and combine equal volumes of these samples to provide a composite sample for analysis. The composite sample should be mixed thoroughly, dried in an oven at 60°C, and pulverised to pass a 20-mesh screen. If an oven is not available, samples can be spread in a thin layer on a plastic sheet or in a shallow plastic pan and dried quickly in the sun. The best procedure for organic carbon determination is the Walkley-Black Method (Boyd & Tucker 1992). The standard procedure requires a modest amount of laboratory equipment, but the Hach Chemical Company markets a portable soil organic carbon kit (Model CEL/700) based on the Walkley-Black Method, which provides results comparable to the standard Walkley-Black procedure (Queiroz & Boyd 1998). To measure soil pH, 10 to 20 g of dry, pulverised sample (sieved through a 0.085 mm screen) should be mixed with 10 to 20 ml of distilled water, stirred intermittently for 20 min, and the pH measured with a glass electrode. Many farmers use a handheld pH–soil moisture tester which can be inserted directly into the pond bottom soil but this device will not measure pH accurately.

Soil organic carbon concentrations in bottom soils of prawn ponds seldom exceed 1 to 2%, and values in excess of 3 to 4% are probably excessive. Organic carbon values can be multiplied by a factor of 2 to provide a rough estimate of actual organic matter. Soil pH values measured as described above should be between 7 and 8.5. Methods for accelerating the decomposition of soil organic matter and for increasing soil pH are described below, in sections 14.2.4.2–14.2.4.7. There is no feasible procedure for lowering a high soil pH.

14.2.4.2 Drying

It is common practice to dry pond bottoms between crops. Drying accelerates the decomposition of organic matter that has accumulated in the bottom during the previous crop, by providing better oxygenation for bacteria. Better oxygenation of the soil oxidises reduced inorganic and organic compounds thus improving soil condition. Drying also kills disease organisms and their carriers that may exist in the soil. A drying period of 2 to 3 weeks is usually adequate. In the rainy season, it may be impossible to dry soil adequately but, as a rule, pond bottoms should be dried well at least once per year (Boyd 1995).

14.2.4.3 Liming and disinfection

In ponds where disease was a serious problem in the previous crops, some farmers treat the pond bottom with an agent to kill disease organisms and reduce the possibility of disease in the next crop. The most effective and economical way of disinfecting a pond is to apply burnt lime or hydrated lime to increase the soil pH above 10 and kill disease organisms (Snow & Jones 1959). A treatment rate of 1000 kg/ha of burnt lime or 1500 kg/ha of hydrated lime is usually sufficient for disinfecting pond bottoms (Boyd 1995). The lime must be spread uniformly over pond bottoms while they are still wet, so that it will dissolve and penetrate the soil mass to raise pH and kill pathogens and their carriers.

Chlorination has also been used to disinfect pond soils. However, the organic matter in pond soils quickly reduces chlorine residuals to non-toxic chloride (White 1992), and 500 mg/L of calcium hypochlorite may be needed for disinfection. To reach this concentration of calcium hypochlorite, about 1000 kg/ha must be applied to the pond bottom to satisfy the chlorine demand as well as leave residual chlorine for disinfection. Thus, chlorination is much more expensive than lime treatment.

14.2.4.4 Oxidants

Nitrates may be applied to pond bottoms to act as a soil oxidant and enhance the decomposition of soil organic matter. Nitrate treatment can increase the redox potential, but it will not appreciably increase the rate of organic matter decomposition. This treatment is suggested only for use in areas of the pond bottom that cannot be dried completely. The nitrate dissolves in soil moisture and penetrates into anaerobic zones in the soil where it serves as a source of oxygen for bacteria (Avnimelech & Zohar 1986), as illustrated in the following generalised equation:

$$4NO_3 + 5CH_2O \text{ (organic matter)} + 4H^+ \rightarrow 2N_2 + 5CO_2 + 7H_2O$$

Oxygen from nitrate is used by bacteria to mineralise organic matter to carbon dioxide and water. The nitrogen gas produced in denitrification is lost to the atmosphere. Sodium nitrate has a basic reaction in ponds because carbon dioxide and water combine to form bicarbonate. This reaction reduces acidity, but sodium nitrate treatment is not a substitute for liming. For most ponds, an application rate of 150 to 200 kg/ha of sodium nitrate or other types of nitrate to pond bottoms is sufficient, but if organic carbon concentrations are thought to be high (or are measured as) above 3 to 4%, twice as much nitrate should be broadcast uniformly over pond surfaces while the soil is still moist. Nitrate can be applied with agricultural limestone in acidic ponds.

Calcium peroxide is sometimes used in Asia to oxidise pond bottoms. This compound releases oxygen spontaneously, even in the presence of DO_2, because of its high oxygenation potential. Nitrate only releases oxygen when the DO_2 concentration and redox potential are low. Therefore, nitrate is more effective as a soil oxidant than peroxide, because it does not release its oxygen until the oxygen is needed to prevent low redox potential.

14.2.4.5 Tilling

Tilling (ploughing) pond bottoms during the drying period can enhance its oxygen content. Heavy-textured soils (clays and clay loams) will benefit more from tilling than light-textured soils (sands, sandy loams, and loams). Tilling should be done with a disc harrow (Fig. 14.2) and limited to a depth of 5 to 10 cm. A rotor tiller is also suitable, but it is destructive of soil structure. Turning ploughs (breaking ploughs) require much more energy to use than disc harrows but are useful when there is an excessive concentration of organic matter on the soil surface because they turn the soil over, burying the surface layer under soil of lower organic matter concentration from deeper layers. Tilling should be done while bottom soils are still moist, but bottoms should be dry enough to support the weight of the tractor tyres and prevent formation of ruts.

14.2.4.6 Sediment removal

It is usually unnecessary to remove sediment from ponds. However, where interior canals fill in, or if particularly large amounts of sediment accumulate

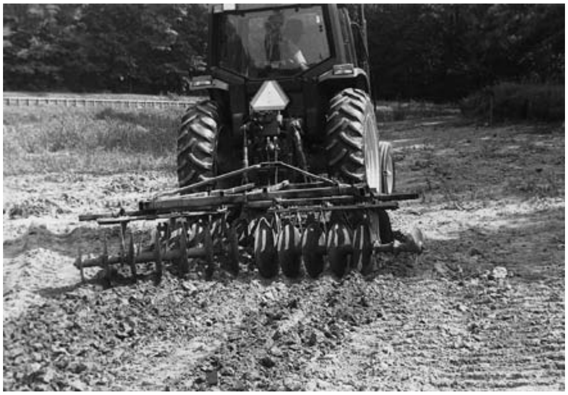

Fig. 14.2 Disc harrow

Table 14.6 Disinfectants and piscicides in marine shrimp ponds. (Source: modified from Clifford, 1992.)

Substance	Disinfectant (D) or piscicide (P)	Recommended doses
Formalin	D	5–10 mg/L
Potassium permanganate	D	2–4 mg/L
Organic silver	D	1–10 mg/L
Organic iodine	D	1–5 mg/L
Malachite green	D, P	nd
Sodium hypochlorite (5.25%)	D, P	100–300 mg/L
Calcium hypochlorite (HTH)(65%)	D, P	10–300 mg/L
Calcium oxide	D, P	1000–5000 kg/ha
Calcium hydroxide	D, P	1000–2000 kg/ha
Rotenone (5%)	P	1–4 mg/L
Potassium cyanide	P	1 mg/L
Limestone + ammonium sulphate	P	1000–1200 kg/ha
Sodium pentachlorophenate	P	0.5–1.0 mg/L
Malathion	P	25–50 mg/L
Endrin	P	nd

nd = Not determined.

in deeper parts of ponds, causing them to lose volume, sediment removal may be necessary. Sediment disposal should be done in a way to prevent the material washing back into ponds or canals after heavy rains and to avoid adverse ecological impacts. Site-specific methods of sediment disposal must be developed for each farm (Donovan 1997).

14.2.4.7 Fertilisation

As a general rule, fertilisation of pond bottoms before filling ponds is not a good practice. Phosphorus in the fertilisers will be adsorbed by the soil and rendered unavailable to the water. The exception is for ponds constructed in soils consisting of a mixture of mineral particles and fibrous organic matter with a wide C:N ratio, which retards the decomposition of the organic matter. In these cases, fertilisation between crops with a nitrogen fertiliser at 50 to 100 kg N/ha can accelerate organic matter decomposition and improve pond bottoms. If pond soils are acidic, agricultural limestone should also be applied. Best results will be obtained if the fertiliser and limestone are mixed into the soil by tilling. Some soils which are very low in organic matter (less than 0.5%) may benefit from applications of organic matter. The disadvantages of manures have been mentioned in section 14.1.5.3 and, for these types of soils, it is preferable to apply 500 to 1000 kg/ha of plant meal, which should also be incorporated by tilling.

14.3 Miscellaneous water and soil treatments

In addition to the standard pond treatments such as fertilisation, liming, and mechanical aeration discussed in section 14.2.4, a number of other treatments are sometimes used in attempts to improve soil and water quality. A few of these treatments are known to be effective under certain conditions, while positive effects of other treatments have not been clearly demonstrated.

14.3.1 Predator elimination

Drying and disinfecting pond bottoms between crops as discussed above improves soil condition and kills disease organisms and their carriers, and these treatments also kill predators. Clifford (1992) presented a list of the main chemical substances and recommended doses to disinfect the bottoms of marine shrimp ponds (Table 14.6). These recommendations can also be used in freshwater prawn farming.

The piscicide rotenone is widely used to eradicate wildfish before ponds are stocked with prawns. Rotenone is a complex organic compound ($C_{23}H_{22}O_6$) which is extracted from the roots of several plants. It interferes with respiration and is extremely toxic to fish at low concentrations such as 0.05 to 2.0 mg/L (Boyd 1990). Its high toxicity is affected by temperature, hardness and water pH. Rotenone may be detoxified with potassium permanganate. Several other chemicals are currently being tested for the potential to eliminate predators in aquaculture. These include high doses of ammonia, potassium permanganate, calcium hypochlorite, calcium oxide, calcium hydroxide with ammonium sulphate, bleaching powder, urea and teaseed cake (which contains saponin, a glucoside that destroys red blood cells and is highly toxic to fish). These products are also toxic to prawns and, when used in ponds, must be allowed to degrade to their non-toxic form before prawns are stocked.

In Latin America and Asia, organo-phosphorus insecticides (guthion, dichlorvos, and phosphamidon) and chlorinated hydrocarbon insecticides have been used to eradicate fish from ponds. Insecticide use is not recommended for prawn culture, not only because of their high human toxicity and the long residual life of some compounds, but also because of their toxicity to prawns, and their possible accumulation in prawn tissues.

14.3.2 Therapeutants

Many therapeutants are used in the hatchery and nursery phases of *M. rosenbergii* culture. However, only a few, namely potassium permanganate, formalin, salt, and copper sulphate, are employed in grow-out ponds. Several diseases are treated with potassium permanganate at doses of 2 to 4 mg/L. Higher doses are not used because this chemical has been shown to be quite toxic to juvenile freshwater prawns (Table 14.7). The toxicity of potassium permanganate to bacteria is decreased in waters with plankton blooms, so application rates must often be increased beyond the target concentration range of 2 to 4 mg/L. Formalin is widely used in aquaculture for the control of fungi and external parasites. It appears to be relatively non-toxic to *M. rosenbergii* PL at concentrations lower than 400 mg/L (Table 14.7). However, it is highly toxic to plankton and pond treatments of 15 mg/L may cause DO_2 depletion in ponds with heavy plankton blooms (Boyd 1990). *Macrobrachium* grows well in low salinities (1–5 p.p.t.; see also section 14.1.3) and salt (NaCl) can be used at doses sufficient to provide therapeutant action. Salt is very cost-effective compared to other chemicals. Copper sulphate ($CuSO_4{\cdot}5H_2O$) is an algicide and also can be used as a therapeutant at concentrations of 0.01 to 0.3 mg/L. It also has bactericidal and fungicidal properties but is frequently replaced by salt, which is cheaper.

14.3.3 Herbicides

Herbicides are used to control aquatic macrophytes. The most widely used are copper sulphate, copper chelates, dichlobenil, diquat, diuron, endothal, and simazine. The manufacturers of each product provide information on effective methods of application and the dosages for killing particular types of macrophytes. Boyd (1990) cited several reviews on the chemical control of macrophytes and presented a summary of herbicide treatment rates for controlling common aquatic weeds. Herbicides should be used to eliminate aquatic vegetation so that plankton blooms can develop and prevent the re-growth of the underwater plants. Unless a plankton bloom is encouraged through fertilisation, macrophytes will simply re-grow as soon as herbicide concentrations decline to non-toxic levels. When used according to recommendations given by the manufacturers, herbicides are seldom directly toxic to aquatic animals, but the decay of plants killed by herbicides may lead to DO_2 depletion. Boyd (1990) recommended dividing ponds with extensive areas of macrophytes into two or more segments and killing the vegetation in the different segments at different times, thus preventing so much vegetation decaying at one time and causing DO_2 depletion. Grass carp (*Ctenopharyngodon idella*) are widely used as a biological weed control agent in freshwater prawn ponds for their ability to eat large quantities of aquatic macrophytes. Polyculture is discussed in detail in Chapter 12.

14.3.4 Phytoplankton control

Phytoplankton control methods can be divided into four categories: algicides, nutrient manipulations,

Table 14.7 Tolerance studies with *Macrobrachium rosenbergii* juveniles.

Substance	Tolerance level (mg/L)	Test[a]	Reference
Tetracycline	594	TL_m	Liao & Guo (1987)
Chloramphenicol	2717	TL_m	Liao & Guo (1987)
Benzalconium chloride	2	–	Liao & Guo (1990)
Benzethonium chloride	6	–	Liao & Guo (1990)
Cetylpyridinium chloride	0.13	–	Liao & Guo (1990)
Potassium permanganate	6	–	Liao & Guo (1990)
Malachite green	1.14	–	Liao & Guo (1990)
Malachite green	2×10^{-8}	SC	Chen *et al*. (1995)
Furazolidone	>300	TL_m	Liao & Guo (1986)
Nitrofurazone	>362	TL_m	Liao & Guo (1986)
Formalin	423	TL_m	Liao *et al*. (1989)
Formalin	4×10^{-6}	SC	Chen *et al*. (1995)
Saponin	168	TL_m	Liao *et al*. (1989)
Cadmium	0.057	–	Chan *et al*. (1992)
Copper	0.05	TAcute	Ismail *et al*. (1990)
Copper sulphate	0.39	–	Liao & Guo (1990)
Copper sulphate	0.012	96-h LC_{50}	Natarajan *et al*. (1992)
Hydrogen sulphide	2.6[b] 4.2[c]	96-h LC_{50}	Jayamanne (1986)
Mercury	0.325	Toxic	Piyan *et al*. (1985)
Zinc	2.97	–	Chan *et al*. (1992)
Azodrin	Non-toxic	–	Tuan & Tan (1992)
Clarosan	0.02	Non-toxic	Avault (1979)
Endosulfan	0.006	96-h LC_{50}	Natarajan *et al*. (1992)
Malathion	0.013	96-h LC_{50}	Natarajan *et al*. (1992)
Methyl-parathion	Trace	Toxic	Tuan & Tan (1992)
Mirex	0.104	24-h LC_{50}	Summer & Eversole (1978)
Monitar	Non-toxic	–	Tuan & Tan (1992)
Sherpa	Trace	Toxic	Tuan & Tan (1992)
Sumithion	Trace	Toxic	Tuan & Tan (1992)

[a] TL_m = average lethal toxicity; TAcute = acute toxicity; 96-h LC_{50} = lethal concentration to 50% of prawns in test after 96 h; SC = safe concentration.
[b] 21-day juveniles.
[c] 2-month juveniles.

polyculture with plankton-feeding fish, and the use of macrophytes. A variety of algicides can be used in ponds, but only three of them, copper sulphate ($CuSO_4 \cdot 5H_2O$), simazine (2-chloro-4,6-bis (ethylamino)-s-triazine) and potassium ricinoleate, have been studied extensively.

Copper inhibits both respiration and photosynthesis in algae, and its toxicity is regulated by the alkalinity and pH of the water. Copper sulphate is more toxic to algae in soft, acidic water than in alkaline water, suggesting that cupric ion is the toxic form of copper (Boyd 1990), and some algal species are more susceptible to copper sulphate than others. Kleinholz (1990) proposed a practical way of calculating the dose of copper sulphate to kill blue-green algae in catfish ponds:

$$\text{Copper sulphate (mg/L)} = \text{total alkalinity (mg/L as } CaCO_3)/100$$

Several techniques have been used to apply copper sulphate to ponds. It can be dissolved in water and sprayed or splashed over the water surface; placed in burlap bags to dissolve while towed behind a boat; or held in cloth bags suspended in ponds so that it is gradually dissolved into the water. A study performed by Liao & Guo (1990) with juveniles of *M. rosenbergii* showed that copper sulphate is toxic above 0.39 mg/L. According to Boyd (1990), application rates in ponds have varied from 0.025 to 2 mg/L, depending on water pH and alkalinity, but methods for determining the best dosage are still to be determined. This author also stated that the concentrations of copper sulphate used for phytoplankton control are seldom directly toxic to fish, but they do kill large numbers of invertebrate prawn food organisms, such as rotifers, cladocerans, and copepods. As prawns are also invertebrates, caution in the use of this compound in prawn grow-out is therefore recommended.

Simazine is a powerful photosynthesis inhibitor that is extremely toxic to phytoplankton but non-toxic to aquatic animals at the treatment rates used for algal control. However, no specific information is available on its effect on freshwater prawns, so caution in its use is suggested. Selective control of blue-green algae is reported with a single or dual treatment at rates of 0.50 and 0.25 mg/L, respectively. Studies by Boyd (1990) showed that DO_2 concentrations usually began to decline about 3 days after treatment, and problems with low DO_2 prohibit the use of simazine except in mechanically aerated ponds.

Its manufacturers have claimed that an algicide containing the active ingredient potassium ricinoleate selectively inhibits the growth of blue-green algae, improves water quality, and eliminates the off-flavour problem in fish and crustaceans. However, research has not confirmed that potassium ricinoleate is effective (Boyd & Tucker 1998). Likewise, Boyd (1990) cited claims that blue-green algae may be controlled with probiotics, but research findings to substantiate these claims are lacking.

Polyculture with plankton-feeding fish is considered as a method of phytoplankton control in freshwater prawn farming. Fish may be regarded as 'sanitary agents' and are used for this purpose by many farmers. However, grazing by plankton-feeding fish may also stimulate phytoplankton production. According to Smith (1988), biological control is the most ecologically sound method for regulating phytoplankton abundance in aquaculture ponds. However, this worker found that plankton-feeding fish usually failed to control phytoplankton, so further research in this area is needed. According to Boyd (1990) there has been some interest in the possibility of cultivating certain species of aquatic plants in eutrophic aquatic systems to remove inorganic nutrients and limit phytoplankton growth. One example is the water hyacinth (*Eichhornia crassipes*) confined to 10 to 25% of surfaces in nutrient-enriched ponds, which directly competed with phytoplankton for nutrients and light.

Water exchange, to flush nutrients and phytoplankton from ponds, has been the most widely used water quality management tool in freshwater prawn ponds. In many *M. rosenbergii* farms a daily water exchange rate of 5 to 10% per day is employed. However, according to Boyd (1990), the most effective way to conduct water exchange is to first discharge pond water and then to introduce replacement water. If new water is added while the pond water is being discharged, up to 50% of the discharged water will be new water. This can reduce the efficiency of water exchange in removing nutrients and phytoplankton. There is also a negative aspect of water exchange, in that it may cause the pollution of the water bodies into which discharge occurs.

Nutrient manipulation, using substances to precipitate phosphorus and limit growth, is a possible way of controlling phytoplankton. Alum (aluminium sulphate) has been used to precipitate phosphorus in eutrophic waters, and gypsum (calcium sulphate) in soft waters. Also, a high nitrogen : phosphorus ratio is thought to enhance the proportion of green algae to blue-green algae. A high-quality feed should be employed so that maximum amounts of organic matter and inorganic nutrients from the feed will be assimilated by prawns and sanitary fishes. Overfeeding should be avoided by controlling feeding rates at reasonable levels to encourage good water quality.

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15
Health Management

Sterling K. Johnson and Sérgio L.S. Bueno

Intensive prawn farming is characterised by the confinement and husbandry of the population in artificially constructed production systems, such as hatchery tanks and grow-out ponds. Various biotic or abiotic factors within intensive systems challenge the health of cultured populations and failure to control them usually leads to feeble or even disastrous production results.

Some suggest (see Bédier *et al.* 1998) that infectious diseases, mainly viruses, have been responsible for the collapse of many marine shrimp farming ventures in the past few years. Important diseases have also been associated with freshwater prawn (*Macrobrachium rosenbergii*) culture which could seriously affect commercial production but virus diseases that would threaten the industry on a large scale have not been reported. Recently, in a paper describing the culture of *M. rosenbergii* and *M. nipponense* in China, Wang & Qianhong (1999) reported that, though they are not as serious as those for penaeids, diseases have already jeopardised the development of freshwater prawn culture. These authors particularly noted that mortalities of broodstock occurred during the overwintering period and that 'white shrimp disease' occurred during the grow-out period. Apart from the obvious negative impact that diseases may pose to prawn production, some diseases compromise marketability of the final product by rendering poor flesh quality (muscular necrosis) or undesirable aesthetic changes (black spot or heavy fouling by epibionts).

Though the body of literature concerning prawn disease contains many excellent scientific works, the composite is small in comparison to that available for many other aquaculture animals. This may be partly due to the growth in the importance of penaeid culture during the 1980s and 1990s, a circumstance that attracted the attention of most of the active crustacean health specialists.

Before describing the specific diseases and other problems that have been found to affect freshwater prawns (section 15.5), relevant information on health and defence mechanisms (section 15.1), diagnosis (section 15.2), prophylaxis (section 15.3) and therapeutics (section 15.4) has been reviewed in this chapter.

15.1 Health and defence

15.1.1 Healthy and diseased animals

Though people say 'poor health' or 'good health', health is not scalar; it is just normal. In prawn culture systems, normal, healthy populations grow, develop, and reproduce according to expectations. That is, they express good performance. Healthy prawns possess a good structural integrity as shown by appropriate colour and a robust body ('condition'). They exhibit a vigorous tactile response and meet various environmental challenges with stamina. Scalar states of disturbed function and disease are found between the non-scalar states of health and death. In typical conditions, the usual homeostatic qualities of animals support a healthy state. Even when external or internal conditions sometimes depart sharply from normal, numerous compensatory mechanisms may be available to restore normal function without a significant cost. One or more of the mechanisms become functional when the animal encounters an internal foreign substance, a potential pathogen, a toxicant, a toxin, an inadequacy of a vital life substance, an environmental extreme, a sudden environmental change, minor wounding or the need to restore any of a variety of deranged capabilities. Thus, an unusual movement of prawns towards the pond bank may only be a manifestation of normal physiological compensation and one that requires no significant cost. Similarly, the presence of healing wounds or infection does not always equate to a state of disease (at least at organism level and above).

There is, of course, a limit to compensatory mechanisms. As conditions exceed the capacity for compensation, breakdown begins (Boyd 1988). Breakdown unfolds more or less quickly causing the animal to reach some stage within a continuum of disturbed function, disease and death. Beyond this limit, recoveries require repair at significant cost and some may not escape permanent disability. In addition to greater vulnerability to present or emerging challenges, animals forced into costly repair assume a disease state and are no longer healthy.

With this paradigm of healthy and diseased animals in mind, it is helpful to recognise that the adaptive qualities of animals are not fixed. The history of an individual and stock may make it more or less able to compensate to prevailing conditions. For example, successive endurance of mild diurnal changes in dissolved oxygen (DO_2) may increase stock tolerance to suppressed oxygen conditions beyond the average, due to adaptive enhancement of its compensatory mechanisms. Important basic differences in adaptive potential occur according to species, developmental stage, size, genotype, maturation stage, and other status.

Dynamic qualities of growing systems, which result from design, management systems and ambient conditions, determine the probability of many disease conditions. Thus, certain infectious diseases are more apt to express in one form of grow-out system than in another. For example, yeast infections occur mainly in winter in Taiwan (Hsu & Liu 1994). Liu *et al.* (1996) found that an infectious yeast caused either no or much less mortality to *M. rosenbergii* at 30°C than at 15 or 20°C when injected with a suspension of the yeast. Another example is given in the trials of Withyachumnarnkul *et al.* (1990) which indicated that survival and growth of juvenile *M. rosenbergii* is better when prawns are grown in continual darkness instead of light–dark cycles.

Some aquatic animal pathogens appear sufficiently virulent to cause disease even in well-managed growing systems. Such pathogens are not known or recognised in grow-out prawn ponds but it is possible that some of the pathogens mentioned below could attain this status in tank systems. Other pathogens are incidental or typically ubiquitous in growing systems but only under opportune circumstances are they capable of causing serious host pathology. Such potential pathogens are often seen and expected in prawn culture.

A customary way of explaining the establishment and further development of infectious diseases, particularly those caused by opportunistic pathogens, is the relationship amongst three interactive factors: a susceptible host, a pathogen exposure, and a proper environmental condition that would more or less favour host susceptibility or pathogen virulence (Snieszko 1973; Pauley 1975). An interaction where each factor does not contribute to additional vulnerability may bring stability to the interaction and disfavour the development of disease. Conversely, a greater or disproportionate interference in the stability by one or more factors may favour the occurrence of disease. For instance, pathogens may become more virulent, environmental conditions may become more stressful and, due to the lessening of resistance, host susceptibility to diseases may increase. In such cases, the full development of pathogenesis is likely to take place with serious impact on the host population.

15.1.2 Defence mechanisms

The crustacean haemolymph, or blood, is essentially sterile and is composed of circulating haemocytes and a fluid portion or plasma. The importance of the haemolymph – particularly the plasma – in gas, nutrient and metabolic waste transportation is well known. Haemocytes and plasma, however, together constitute a major framework associated with the clotting mechanism, wound repair, restoration of damaged tissue and defence response.

The defence mechanisms shared by crustaceans and all other arthropods differ from those of the vertebrates in that there is no production of immunoglobulins. In all arthropods, humoral and cellular defence mechanisms involve the direct participation of the circulating haemocytes and dissolved factors in the plasma. Although the defence response in arthropods lacks the antigen–antibody specificity found in vertebrates, it nonetheless is efficient in recognising the non-self and taking prompt actions to immobilise and eliminate invading organisms.

The exoskeleton, or cuticle, represents a natural physical barrier to invading organisms. The crustacean cuticle covers all exposed body surfaces and also provides the lining of the foregut and the hindgut. The portion that covers the gills lacks epicuticle, thus permitting interchanges and the portion lining the gut lacks the lipid outer layer to the epicuticle thus allowing permeability. The midgut mucosa, although not lined with cuticle, also represents a physical obstacle to the resident intestinal flora in the gut lumen.

The structural integrity of these barriers, however, may be physically compromised by a myriad of injuries. Lesions in the exoskeleton, for example, represent an open door for opportunistic and pathogenic organisms and provide access to internal tissues and to the haemocoel cavities (Fig. 15.1 – A). Factors on the surfaces of invading micro-organisms or contained in their releases are recognised as non-self by pattern recognition proteins, which trigger an immediate defence response involving cellular and humoral factors (Söderhäll & Thörnqvist 1997).

One possible route of defence is characterised by the clearance of small invaders through phagocytosis by haemocytes and fixed phagocytes (Fig. 15.1 – B). The phagocytic action of haemocytes is well documented and it has been demonstrated *in vivo* (White & Ratcliffe 1982; Smith *et al.* 1984) and *in vitro* in decapod crustaceans (Paterson & Stewart 1974; Smith & Ratcliffe 1978). Clearance by phagocytosis is a very efficient mechanism, by which most invading or experimentally injected bacteria are eliminated from the haemolymph within a few minutes or hours (White & Ratcliffe 1982; Martin *et al.* 1993; Sung *et al.* 1996).

Another defensive route is performed by the activation of the proPO (prophenoloxidase) system which involves a series of cascade enzymatic reactions that culminates with the synthesis of melanin (Unestam & Söderhäll 1977; Söderhäll & Unestam 1979; Söderhäll 1981, 1982) (Fig. 15.1 – C). This defensive route is responsible for the immobilisation, nodule formation or encapsulation and melanisation of invading micro-organisms, metazoan parasites and foreign particles that are too large to be phagocytosed by haemocytes. Exogenous elicitors, associated with the invaders themselves, initiate the proPO system reaction (Fig. 15.1 – D). Organic compounds in the cell wall of micro-organisms are known to induce and enhance a defence response. Some of these compounds have already been identified in the cell walls of Gram-negative bacteria (lipopolysaccharides or LPS) (Söderhäll *et al.* 1986), of Gram-positive bacteria (peptidoglycans) (Johansson & Söderhäll 1989), and of fungi and algae (β-1,3-glucan carbohydrates) (Unestam & Söderhäll 1977; Smith & Söderhäll 1983; Ashida & Söderhäll 1984; Smith *et al.* 1984). β-1,3-glucans are readily recognised as non-self by the crustacean humoral and cellular defence system and it has been demonstrated that the presence of these polysaccharides enhances phagocytosis (Smith & Söderhäll 1983). Trypsin has been experimentally demonstrated to elicit the activation and the enhancement of the phenoloxidase activity in *M. rosenbergii* (Sung *et al.* 1998).

The recognition interface between the invading micro-organisms and the semi-granular haemocytes is probably enhanced or intensified by the opsonic action of lectins in the plasma (Söderhäll & Cerenius 1992). Lectins have been found in the haemolymph of some decapod crustaceans, including *M. rosenbergii* (Vasta *et al.* 1983; Vazquez *et al.* 1997), penaeid shrimp (Ratanapo & Chulavatanpol 1992; Vargas-Albores *et al.* 1993; Perazzolo & Barracco 1997) and lobsters (Imai *et al.* 1994).

The semi-granular haemocytes are probably the first line of defence to respond against invading organisms by releasing (exocytosis) in the plasma a serine protease (ppA, the proPO-activating enzyme), an adhesion factor glycoprotein (76 kDa) and the pro-enzyme prophenoloxidase (proPO, the inactivated form of the enzyme phenoloxidase, or PO) (Fig. 15.1 – E). In the presence of the elicitors in the cell wall of the micro-organisms, the ppA and the adhesion factor become active. The activation of proPO into PO is mediated by the active form of ppA (Aspán *et al.* 1990b). The PO is responsible for the oxidative reaction of phenols into quinones, which, in turn are non-enzymatically polymerised in melanin (Johansson & Söderhäll 1989). This

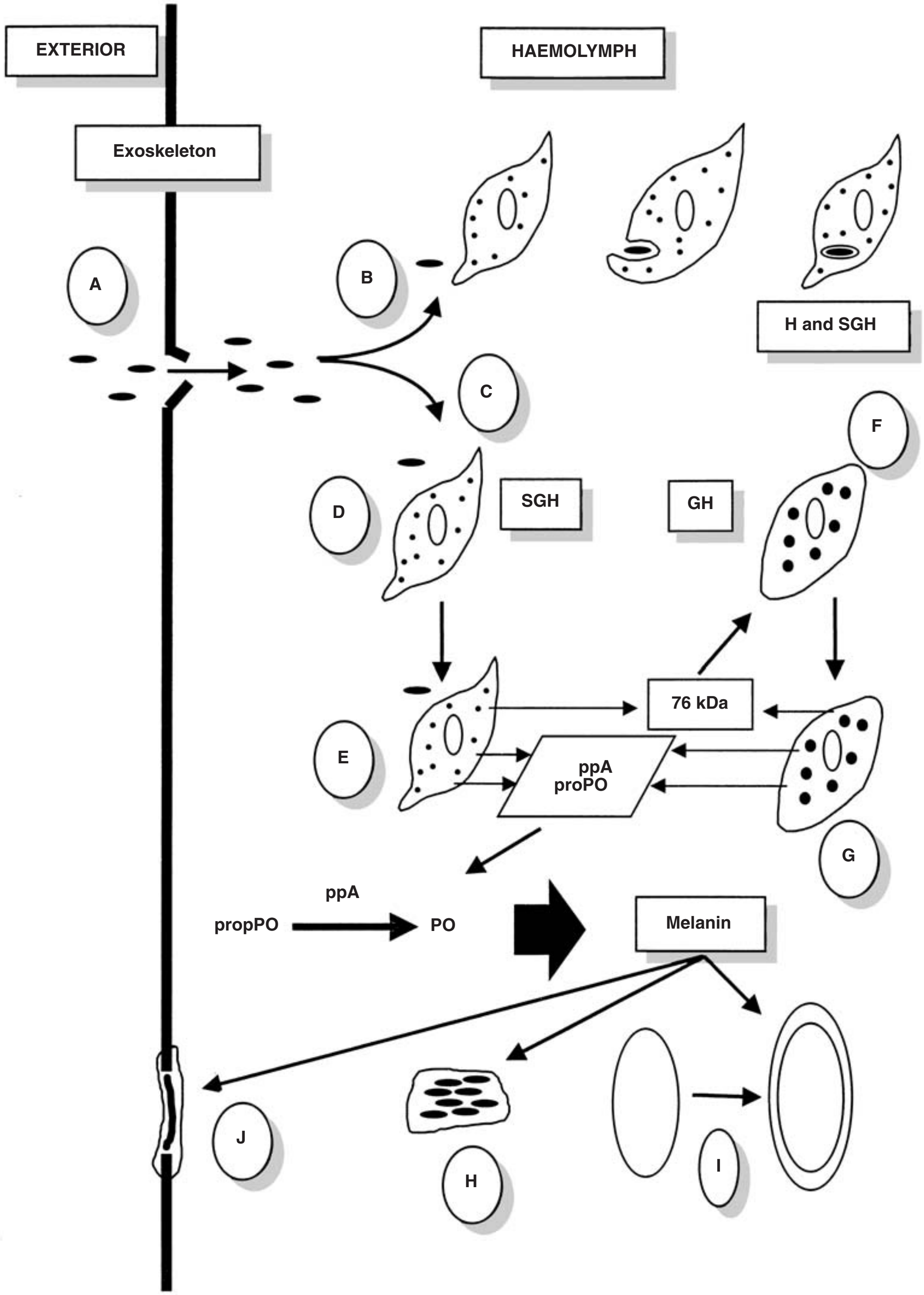

Fig. 15.1 Generalised representation of defence mechanism in decapod crustaceans. Note: see text (section 15.1.2) for explanation of steps A through J. Abbreviation of types of haemocytes: H = hyaline cells; SGH = semi-granular cells; GH = granular cells; PO = phenoloxidase; ppA = proPO-activating enzyme; proPO = prophenoloxidase; 76 kDA = adhesion factor. (Source: based and modified from Johansson & Söderhäll, 1989.)

dark-coloured pigment acts as a fungicide (Söderhäll & Ajaxon 1982) and its formation is frequently associated with inflammatory processes in crustaceans (Lightner & Redman 1977).

The adhesion factor, 76 kDa, mediates the aggregation and adhesion of haemocytes in the formation of nodules (Fig. 15.1 – H) and capsules (Fig. 15.1 – I) that will promote the immobilisation and/or isolation of invading organisms (Johansson & Söderhäll 1988; Kobayashi *et al.* 1990). Melanisation of injured tissues or lesions (Fig. 15.1 – J) is important during the process of tissue restoration. The adhesion factor also promotes exocytosis of the granular haemocytes (Fig. 15.1 – F) (Johansson & Söderhäll 1989) resulting in the release of an additional load of proPO, ppA and 76 kDa in the plasma, thus amplifying the defence response (Fig. 15.1 – G). The proPO system possesses a self-regulating mechanism, represented by inhibitors in the plasma that inhibit ppA activity (Aspán *et al.* 1990a).

It has also been demonstrated that the PO-system activity requires the presence of divalent cations (Ca^{2+} and Mg^{2+}) and is temperature-dependent (Smith & Söderhäll 1983; Sung *et al.* 1998). The PO activity may also vary in decapod crustaceans. Sung *et al.* (1998) reported that PO activity at 37°C was 2.7 times higher in *M. rosenbergii* as compared to *Penaeus monodon*.

An effective defence response is characterised by the decrease in the number of circulating haemocytes (Smith *et al.* 1984). According to Martin *et al.* (1993) the rapid decrease of circulating haemocytes during a defence response is accompanied by a significant increase of mitotic activity in the haematopoietic tissue. These authors also reported that the attachment of haemocytes on to a surface (similar to *in vitro* experiments) is an important condition for phagocytosis to occur efficiently and, therefore, suggest that haemocytes would settle out of circulation (hence their decrease in circulation) and attach to internal tissue surfaces (e.g. in the gills, heart or digestive gland) containing previously adhered bacteria. Recovery in the number of circulating haemocytes may occur within 24 h (Smith & Söderhäll 1983). Martin *et al.* (1993) suggested that this recovery may be accomplished by the returning of settled haemocytes to circulation again, and the release of newly produced haemocytes from the haematopoietic tissue.

Haemocytes also support the clotting of crustacean blood. When normal quantities are present in the circulating blood, clotting is sufficiently rapid to contain the loss of blood into the liquid environment when wounds and lesions occur.

Necrotic and encapsulated tissues in gill (Doughtie & Rao 1983) and sub-cuticular spaces are removed, along with old cuticle, during moulting. This mechanism of removal may be both defensive and restorative. The caridean gill structure is quite different from that of penaeids and is less likely to show areas of necrosis in pond stocks (S.K. Johnson, general observation). Grooming or preening of body surfaces is thought to be responsible for control of some otherwise burdening epibionts (Bauer 1981; Jones & Lester 1993).

15.2 Diagnosis

15.2.1 Recognition and diagnosis

A diagnosis represents the best attempt to encompass all the facts in describing the true nature of a problem. This means that a consideration of the state of the culture system in terms of its present condition and immediate history should augment diagnostic information concerning the culture animal and its population. Knowledge of common agents and how the diseases they cause initiate, develop and enlarge is quite helpful in the analysis and synthesis of the problem. Given a narrow time frame and the necessary limitation to our capabilities for analysis, we usually comprehend only in part the complexity of conditions or variables that predispose or cause a disease condition. Nevertheless, the correct diagnosis of a disease is essential to the choice of proper and specific interventions that must be taken to resolve a disease problem.

The ability to discern the normal condition from the abnormal is of vital importance in prawn pathobiology. A good knowledge of morphology, normal tissue structure and the prawn's general biology is necessary. The discernment process also benefits from knowledge of ontogenetic changes during the life span of prawns. For example, changes in feeding habits and general behaviour according to life stages (larvae, juveniles and adults), changes during the moult cycle and changes in gonadal development and maturation.

The occurrence of deviant conditions warns of the development of a disease event. These may manifest as gross signs (e.g. lethargy, unusual swimming behaviour of larvae and postlarvae (PL), changes in body colour, refusal to feed, and exceptional mortality), or lesions at the tissue level which are observable by means of histopathological analysis. Though the presence of sudden mortality makes disease quite apparent, a variety of more subtle indications are also quite valuable in the early detection of disease. Individual diseased animals often exhibit characteristic manifestations and their populations conspicuous patterns of disease development.

15.2.2 Diagnostic tools

Early diagnosis is vital to avoid the full development of epizootics. Methods used in disease diagnosis must be able to provide reliable information which will lead to a correct identification of aetiological agents (Reddington & Lightner 1994). Methods currently available for the diagnosis of prawn diseases provide vital information about causative agents. These methods range from the simple evaluation of gross signs to highly specific and sensitive methods which rely on molecular biological techniques.

Conventional diagnostic tools include wet-mount preparations, which are most commonly used on-farm, and histological and microbiological examinations which are usually conducted in laboratories (Lightner 1996). The specific application of these techniques to freshwater prawn farming has been detailed by Bueno & Gastelú (1998).

Recently, molecular-level tests of diagnostic value are being developed for the determination of important diseases in aquaculture. These tests, which rely on the use of monoclonal antibodies and DNA probes and the amplification of target DNA by the polymerase reaction, give very sensitive results in the detection of specific agents. Immunoassay methods which include monoclonal antibodies have a strong potential for pathogen determination in prawn culture. Several DNA-based diagnostic tools (dot-blot hybridisation and *in situ* hybridisation) have been developed and are commercially available for the detection of several viruses of penaeid shrimp (Reddington & Lightner 1994). However, except possibly for white spot virus (ShrimProbe®, DiagXotics, Inc., Wilton, CT, USA), no similar DNA-based diagnostic tool has been developed for use in *Macrobrachium* culture.

15.3 Prophylaxis

15.3.1 Definition

According to Bell (1992), prophylactic treatment means that a chemotherapeutant is routinely administered prior to clinical signs of a particular disease, namely where an anticipation of occurrence is often and best supported by historical records. The use of drugs (antibiotics) as a preventative in crustacean hatcheries is widespread but their use in prawn grow-out systems is impractical due to cost. Chemical compounds routinely used in prophylaxis include disinfectants and sanitisers (iodine, active chlorine) and herbicides (e.g. Treflan®, for *Lagenidium* treatment in hatchery tanks). The broader definition of prophylaxis encompasses other forms of water sanitation (ozone, ultraviolet (UV) radiation, mechanical filtration, dehydration and cleaning of equipment, exclusion of inoculum); these are husbandry practices that result in favourable system conditions and well-fed stock, and strategies that support the presence of disease-resistant stock.

15.3.2 Husbandry dynamics

The maintenance of good water quality in the hatchery is of utmost importance (see Chapter 14). Feeding practices, efficient transformation and removal of wastes, and general sanitation all contribute. Ozonation, chlorination and radiation with UV lighting efficiently reduce the quantity of pathogens in marine shrimp and freshwater prawn culture water (Danald *et al*. 1979; Daniels *et al.* 1992). Removal of suspended particles by sand filtration or other means prior to the application of these methods improves effectiveness. Daniels *et al.* (1992) recommended that, before stocking a precleaned tank with newly hatched prawn larvae, the aerated water medium should be sterilised with chlorine. Larvae are added later, after no residue of active chlorine is detected in the water. Providing culture conditions that avoid a prolongation of the hatchery cycle usually reduces the possibility of disease occurrence.

15.3.3 Sanitation

To be successful, all growing units, especially hatcheries, must be thoroughly cleaned and disinfected before a new production cycle is initiated. The importance of thorough cleaning to the effectiveness of subsequent sanitation steps can hardly be over-emphasised. Assuming that sanitary efforts have brought about a complete disinfection of pathogens rather than their suppression, only strict avoidance measures that complement further sanitary practice will prevent the reintroduction of the pathogen. This implies that all personnel in all production areas must observe hygienic control so that efforts will not prove futile. The prevention of introductions and subsequent transmissions of undesirable pathogens, via berried females, eggs, larvae and larval food (decapsulation of *Artemia*), is accomplished by various methods which are described in the literature (see, for instance, Aquacop 1983; Sorgeloos *et al*. 1983; Daniels *et al*. 1992; Brock 1993; New 1995). The use of antibacterials and antibiotics to suppress the bacterial flora of water and animal surfaces is a common practice in crustacean hatcheries. Presumably, there is also some degree of intake and absorption into the animals. This practice presents some risks (see section 15.4.2).

15.3.4 Quarantine facilities

The possibility of introducing pathogens into geographical areas without a history of their occurrence has been a concern and major problem for aquaculture generally. Domestic and international trading in *M. rosenbergii* PL and broodstock is commonplace and frequently carried out without any previous examination of the population for clinical diseases and without sanitary certification. Although *M. rosenbergii* farming has been practised for many years in several countries that are out of the natural range of the species, it should not be forgotten that this prawn is an exotic species in those areas and therefore poses some environmental risk.

Quarantine facilities have an important role in the safety of species introductions. During quarantine, animals remain under constant observation for the detection of any gross signs that would indicate the presence of disease, and samples are periodically taken for analysis by different diagnostic methods. These observations may be supported by enhancement procedures that subject the captive population to optimised stressful conditions thereby lowering prawn resistance and consequently permitting disease expression by otherwise 'hidden' agents (Bell & Lightner 1992). Once it has been reasonably established that no diseases of major concern are present, the confined population may then be transported to the final destination. Quarantine is also practised to prevent the introduction and transmission of diseases at the farm level in a variety of ways, including the provision of special tanks or rearing systems that are temporarily or permanently dedicated for quarantine purposes.

15.4 Therapeutic treatment

15.4.1 Chemotherapy

In contrast to prophylactic treatments where applications are part of the management routine, chemotherapeutic treatments should only be applied when an accurate diagnosis of the disease is available (Bell 1992). Chemotherapy is thus a strategy that responds to an emergent disease situation following its diagnosis. If applied soon enough, chemotherapy can sometimes minimise mortality. Use of chemotherapy is often impractical due to the delay required to reliably determine the presence of a causative agent. In comparison to the prophylactic treatments that are often practised in crustacean hatcheries, corrective treatments are less likely to contribute to the risk of inducing disease resistance.

Chemotherapy in prawn farms is performed at the population level, except in the specific case of broodstock (berried females) which may be individually treated in small containers after their transfer from ponds (or capture fisheries) to indoor holding tanks. Static immersion in treatment baths is usually preferable for drug delivery in tanks.

Though expensive, pond populations can be treated with drugs via oral delivery through the use of medicated feeds.

15.4.2 Risks and legal responsibilities

The use of antibiotics and antimicrobial drugs is widespread in aquaculture; prawn farming is no exception. Many countries have no regulatory processes for aquaculture drugs and therefore substances of use lack approvals or other controls. Nevertheless, managers of shrimp and prawn enterprises frequently have no choice but to use a generalised assortment of drugs to avoid great production losses (Bell 1992).

A specific major concern is that drug contamination may occur in the food products of crustacean culture. Many countries are addressing the risk to humans by developing and implementing plans which follow the Hazard Analysis and Critical Control Point (HACCP) concept. An excellent synopsis of methodologies for shrimp farming is given in Suwanrangsi *et al.* (1997). Another risk that has the attention of regulators is the usually undetermined influence of culture system discharges (effluents) on adjacent environments.

The indiscriminate or inadvertent use of antibiotics poses the possibility of the development of resistant bacterial strains, which would present an immediate problem for prawn hatcheries and farms. This practice also introduces an undefined human risk because most of the drugs are also used in human medicine. In some countries most drug applications are forbidden or strictly controlled. For example, chloramphenicol is subject to extreme regulation in the USA, and veterinary and medical practitioners there may possess only small amounts in stock. Whilst chloramphenicol is effective against a broad spectrum of bacteria, it is very effective against typhoid fever in humans and the development of resistance can be, and is, a worldwide medical problem. Additionally, human uses must consider the toxicity of chloramphenicol which causes aplastic anaemia, a bone marrow condition that may become irreversible (Merck 1992).

15.4.3 System restoration

Many interventions that maintain and restore a healthy system, all of which would positively influence a culture stock, are described in many other chapters of this book. For example, in the case of an apparent disease event in hatcheries, immediate consideration should be given to inputs. Replacement of hatchery tank water, either at an enhanced rate or with another appropriate supply, provides a new environment to some extent. Food may also be changed or replaced. The complete drying of equipment, along with adequate cleaning and the use of disinfectants between larval cycles, usually improves production and controls disease incidence. To a certain extent, similar restorative efforts may also improve pond production.

15.5 Diseases

This section presents, for some important diseases reported for *M. rosenbergii*, a brief description, preventive measures, and prophylactic and therapeutic treatments. Information on applications and dosages for several drugs presented in this section were taken from various reports and scientific papers and do not imply any product endorsement or recommended use by the authors of this chapter. Additional information on these and other less important prawn diseases are available in review papers (Johnson 1982; New 1990; Tonguthai 1992; Brock 1993; New 1995; Bueno & Gastelú 1998).

15.5.1 Infectious and parasitic diseases

15.5.1.1 Viral diseases

A *Macrobrachium* hepatopancreatic parvo-like virus (MHPV) causes disease in *M. rosenbergii* but has not been associated with important prawn morbidity or mortality (Anderson *et al.* 1990a), and apparently represents no major concern to prawn farmers. The definitive diagnosis of MHPV requires the histological demonstration of a characteristic inclusion body within the hypertrophied nucleus of the affected cells of the hepatopancreas epithelia (Anderson *et al.* 1990a). These cytopathological characteristics resemble those observed in hepatopancreatic parvovirus (HPV) infection, which causes a similar viral disease of penaeid shrimp (Lightner & Redman 1985; Lightner 1988b; Roubal *et al.* 1989). *Macrobrachium* hepatopancreatic parvo-like virus of *M. rosenbergii*, however, is distinguished from shrimp HPV by an *in situ* hybridisation test for genomic HPV that shows no positive reaction with MHPV preparations (Lightner 1996).

Another parvo-like virus, tentatively named *Macrobrachium* muscle virus (MMV) has been reported from southern Taiwan (Tung *et al*. 1999). The virus infects muscle tissue only, and infected tissue becomes opaque with progressive necrosis. Basophilic inclusion bodies are seen in the cytoplasm of striated muscle cells. Outbreaks occur within 10 days of transfer of PL to outdoor ponds, where mortality may exceed 50% within 2 weeks.

A member of the white spot virus complex, white spot syndrome baculovirus (WSBV), is known to infect *M. rosenbergii* and cause disease manifestations (Lo *et al.* 1996; Nunan *et al*. 1998; Peng *et al*. 1998). The cuticular epidermis, stomach, gills and hepatopancreas constitute target tissues of WSBV infection in *Macrobrachium* sp., as detected by *in situ* hybridisation (Chang *et al*. 1998). In Taiwan, Wang *et al*. (1998) used *Penaeus monodon* tissue that was infected with WSBV as a food challenge to several decapods. Results suggested a relative non-susceptibility of the young *Macrobrachium* sp. used in the study. In experimental studies by Rajendran *et al*. (1999), a white spot syndrome virus (WSSV) obtained from *P. monodon* from the southeast coast of India was used to challenge *M. rosenbergii* and several other crustaceans. Challenge by viral injection and feeding with infected tissue resulted in 100% survival and no clinical symptoms for up to 70 days. These animals, however, could be used to infect susceptible *P. monodon*, suggesting the possible role of carrier or reservoir. In a similar study, Hameed *et al.* (2000) used a viral inoculum obtained from *P. monodon* with WSSV to test the relative susceptibility of two penaeid and three freshwater prawn species. All species tested had significant mortality except *M. rosenbergii*, even when the latter was given multiple injections of increasing dosage. Though not fully established as important in prawn culture, white spot is a very serious disease in penaeid shrimp in Asia.

In the late 1990s hatchery-reared populations of *M. rosenbergii* in Martinique (French West Indies) experienced heavy mortalities attributable to viral disease. The disease agent, apparently a nodavirus, has subsequently been isolated. A whitish tail is the essential clinical sign. The principal histopathological manifestation is the presence of basophilic cytoplasmic inclusions in connective cells throughout the tissues and organs (Arcier *et al*. 1999; J. Bonami, pers. comm. 1999).

15.5.1.2 Bacterial diseases

Common bacterial diseases of *M. rosenbergii* express as cuticular or systemic infections. The bacterial genera implicated in reports are also known to be present as part of the normal gut microflora (Colorni 1985) as well as in the water column and tank walls of commercial hatcheries (Anderson *et al*. 1989). These bacteria, however, are also opportunistic and may become pathogenic when adverse rearing conditions are present. Little has been done to single out important bacterial species as consistent problems in prawns and more research is required to properly document the pathogenesis of the diseases they cause.

Black spot (brown spot, shell disease) affects all life stages of *M. rosenbergii*. The presence of one to several focal melanised lesions on the general body surface is the most distinct gross sign (Fig. 15.2). Mechanical damage predisposes the disease by providing a portal of entry for infection by opportunistic bacteria. The chitinolytic action of certain

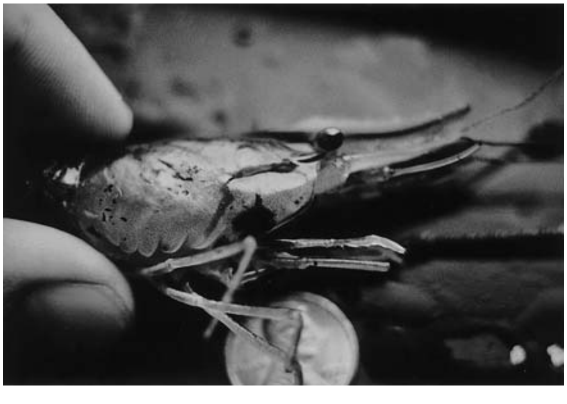

Fig. 15.2 Common sites of melanisation and necrosis. Note: common sites are around the gill bailer base, the tissue lining inside of the carapace adjacent to the gills (dark line), anywhere on the surface where weak points occur on the cuticle (black dotting) and, in tank systems, especially appendage tips, wounds and impact points such as the dorsum of the tail (not shown).

bacteria is thought to support their greater virulence (Delves-Broughton & Poupard 1976; Chan 1979). The erosion thus produced in some lesions further exposes the epithelial layer and connective tissue underneath. The typical dark colour of such lesions is due to local formation and deposition of melanin. In composite, this is a consequence of inflammation, the activation of the proPO system defence response against the invading bacteria (and to other secondary pathogens like the fungus *Fusarium*) and tissue restoration. Gram-negative bacteria within the genera *Vibrio*, *Pseudomonas*, and *Aeromonas* are frequently associated with and isolated from black spot lesions (El-Gamal *et al.* 1986; Hipólito *et al.* 1996).

If the black spot lesions are confined to the exoskeleton, the problem may simply disappear with the next moult. Although all life stages of *M. rosenbergii* are susceptible to black spot, the characteristic lesions are more frequently observed in juveniles and adults (Brock 1993) than in the larvae, which moult more frequently. On occasions of further progression of this syndrome, bacteria may reach the haemocoel via deep lesions and spread throughout the body.

Development of black spot is frequently associated with poor husbandry, overcrowded conditions and poor sanitation (Hipólito *et al.* 1996). Preventive measures should therefore be focused on the maintenance of optimum water quality, adequate feeding, adequate larval and adult stocking densities, and careful handling (Brock 1993). El-Gamal *et al.* (1986) reported that prophylactic treatment of black spot includes the use of an immersion bath with 10 p.p.m. oxolinic acid for 1 hour. Oxolinic acid is a synthetic antimicrobial agent (a quinolone) with a wide spectrum of activity against Gram-negative bacteria (Alderman 1988). Daniels *et al.* (1992) found that oxolinic acid was useful in suppressing bacterial problems in research tanks without the suppression of nitrifying bacteria that are important for biological filtration efficiency.

Nifurpirinol (commercial name: Furanace or Prefuran®), has been used as a potential chemotherapeutant for treating bacterial diseases, such as black spot. The use of an immersion bath with 2.0 p.p.m. Furanace for up to 96 h has been suggested for the treatment of black spot in *Macrobrachium acanthurus* (Martínez *et al.* 1982). Exposure to concentrations as high as 2.0 or 2.5 p.p.m. causes no deleterious effect on adults of *M. rosenbergii* (Delves-Broughton 1974) and *M. acanthurus* (Martínez *et al.* 1982), whilst a much lower concentration is efficacious in inhibiting the growth of some opportunistic bacteria (Delves-Broughton & Poupard 1976). However, Brock (1993) recommended that this syndrome should not be treated with chemicals.

Bacterial necrosis, as described by Aquacop (1977) and Le Bitoux (1988), is similar to black spot in terms of gross signs but is associated with the larval phase only (more serious at stages IV and V) and involves the necrosis and melanisation of whole body appendages. Other gross signs of the disease are an empty gut and the bluish colour of affected larvae (Aquacop 1977). An association of the disease with the presence of *Pseudomonas* and the filamentous bacteria *Leucothrix* has been suggested (Bueno & Gastelú 1998). Development of bacterial necrosis is rapid (Le Bitoux 1988) and, if untreated, can be responsible for great larval losses within a few days. Onset has been linked to a decrease in larval resistance which follows sudden changes in water temperature and larval manipulation; thus any preventive measures need to be aimed towards the control of these stress-inducing factors (Le Bitoux 1988). Reports of treatment with chemotherapeutants include the use of nifurpirinol, in variable concentrations according to various authors (Aquacop 1977; Brock 1983; Le Bitoux 1988; Bueno & Gastelú 1998), 0.65 to 1.0 p.p.m. erythromycin, 2 p.p.m. penicillin-streptomycin (Aquacop 1977; Le Bitoux 1988) and 1.5 p.p.m. chloramphenicol (Bueno & Gastelú 1998).

Bacterial involvement may be secondary (rather than a direct cause) in the cases of necrotic appendages of *Macrobrachium* larvae and may be associated in some way to similar manifestations that are seen in other larval disease syndromes. Brock (1993) made this point by citing experiences in Hawaii and Malaysia.

Bueno & Gastelú (1998) reported a systemic infection of *M. rosenbergii* larvae by a luminescent *Vibrio* species in Brazil. The vibriosis causes a characteristic glowing appearance of moribund and dead larvae. Such infections are known to occur widely in penaeid hatcheries. The luminescent bacterium *Vibrio harveyi* has been isolated from affected *Macrobrachium* larvae (Tonguthai 1992, 1997). Luminous bacteria isolated from penaeid shrimp in Indonesia were virulent to *Penaeus (Fenneropenaeus) indicus* but much less virulent and unable to cause significant mortalities in *Macrobrachium* larvae (Prayitno & Latchford 1995). Tonguthai (1997) associated high prevalence of luminescent bacteria in waters surrounding hatcheries in Thailand with a high prevalence of luminescent bacterial disease in hatcheries. It is likely that the luminescent character of some bacteria makes them more recognisable when systemic bacterial infections occur. This would suggest that systemic infections in hatcheries by non-luminescent bacteria may be more prevalent than is commonly realised. Vibriosis can cause great losses of larvae in hatcheries. Preventive measures similar to those mentioned for black spot and bacterial necrosis have been recommended. Bueno & Gastelú (1998) suggested a water treatment with 2.0 p.p.m. chloramphenicol and 2.0 p.p.m. furazolidone for 5 to 7 days, once vibriosis is diagnosed.

Gram-positive bacteria infect crustaceans less commonly than Gram-negative. A systemic infection by the Gram-positive bacteria *Mycobacterium* was diagnosed in a broodstock female kept in captivity for more than 7 years (Brock *et al.* 1986). Cheng & Chen (1998b) reported isolation of an *Enterococcus*-like bacterium from the musculature of *M. rosenbergii* in Taiwan. Such isolates are common in the warm season. Infected prawns show necrosis of tissues in the hepatopancreas and musculature. The pathology begins in the head and advances towards the tail, giving the animal an opaque appearance. Experimental challenge of healthy prawns by injection of the bacterium and subsequent exposure to environmental conditions showed that infection is exacerbated by high pH (8.8–9.5) and temperature (33–34°C). Low salinity (5 and 10 p.p.t.) appeared to have a favourable effect upon survival (Cheng & Chen 1998a).

15.5.1.3 Rickettsial disease

Rickettsial disease has been implicated in the so-called 'white post-larval disease' syndrome which seriously affected post-larval production in Puerto Rico in the early 1990s and demanded complete clean-up of hatcheries to eradicate the problem (Lacroix *et al.* 1994). In Brazil, a rickettsia has also been linked to high mortalities (up to 95%) of larval stages IV and V which also showed distinct atrophy of the hepatopancreas (Da Silva *et al.* 1989). The use of the antibiotic oxytetracycline (10 p.p.m.) and the antibacterial furazolidone (10 p.p.m.) together as prophylactic measure is said to be helpful (Da Silva *et al.* 1989). Canuto e Silva *et al.* (1989) also reported the prophylactic use of lime (CaO) in *Macrobrachium* hatcheries prior to stocking larvae in hatchery tanks.

Considering the frequency with which rickettsias are now being reported in crustaceans, it is apparent that rickettsial diseases are potentially more important than was once understood. Heretofore histopathologists may have often overlooked the presence of rickettsias, due to their small size and the lack of staining contrast that they show in preparations for routine histology.

15.5.1.4 Fungal infections

Fungal infection by the phycomycete *Lagenidium* in *M. rosenbergii* hatcheries has been responsible for the decimation of larval populations in less than 24 h (Gomes *et al.* 1988). The infection can be readily diagnosed by the observation of an extensive mycelial network visible through the exoskeleton of moribund and dead larvae (Fig. 15.3). Several chemical drugs have been tested as prophylactic treatments of *Lagenidium* (see Lightner 1988b). Perhaps the most widespread compound still in use in penaeid and *Macrobrachium* hatcheries is the herbicide trifluralin (Treflan®, DowElanco) (Armstrong *et al.* 1976; Lightner 1988c; Bueno 1989). Maintaining concentrations of 10 to 100 p.p.b. in the larval tanks is said to be an effective control for *Lagenidium* in penaeid hatcheries (Lightner 1988c). The use of a 2% solution of tincture of Merthiolate® (20 p.p.m. active ingredient) has also been reported to effectively inhibit *Lagenidium* growth (Colorni 1985).

Similar to opportunistic bacteria, the imperfect fungus *Fusarium solani* takes advantage of openings provided by mechanical trauma of the cuticle (Burns *et al.* 1979) or damage associated with idiopathic muscle necrosis. An intensive defence response (activation of the proPO system) culminates with a strong melanisation of the affected area. Demonstration of typical canoe-shaped macroconidia in wet mounts or histological preparations is important for the correct diagnosis of the *Fusarium* infection (Lightner 1988a). *Saprolegnia*

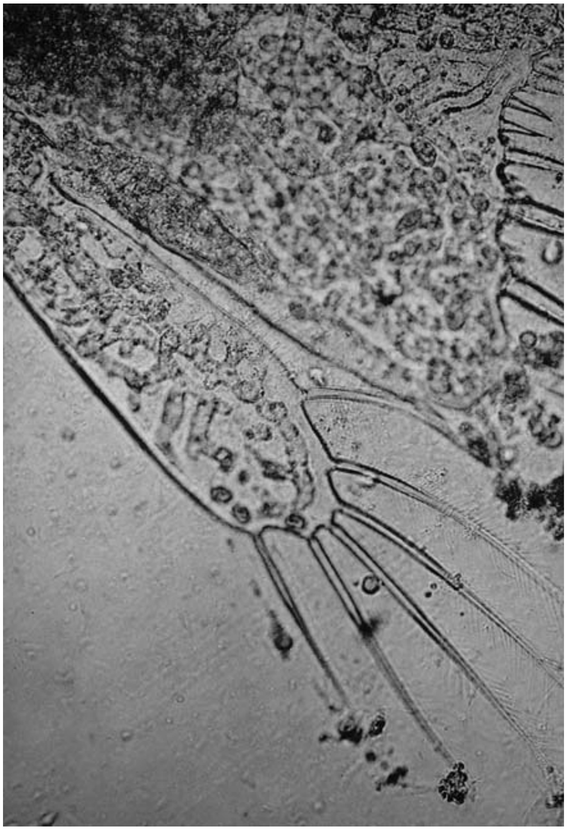

Fig. 15.3 Hyphae of *Lagenidium* filling body spaces of a larva

(Chien 1976) and other fungal genera may also invade injured prawns.

Heavy mortalities of *M. rosenbergii* in Taiwanese grow-out ponds in the early 1990s have been associated with infections caused by the yeasts *Debaryomyces hansenii* and *Metschnikowia bicuspidata* (Chen 1995; Sung *et al.* 1998). Affected tissues included the gills, muscle, hepatopancreas and haemocytes (Chen 1995). The yellowish, bluish or greyish colour of the musculature, and a reduced resistance to the effects of stressful conditions, are indicative of diseased animals (Chen 1995). The occurrence of the disease has been associated with the accumulation of organic matter in the pond bottom and eutrophication in grow-out ponds (Chen 1995) and, perhaps more importantly, water temperatures lower than that optimal for the species (Hsu & Liu 1994). Therefore, possible preventive measures are careful pond preparation (removal of organic load from the bottom), not overfeeding, management practices (water exchange, circulation and aeration) which provide better water conditions, and careful attention to temperature levels.

Recent work with a large sampling of isolates in Taiwan has helped to remove confusion about the identity of prawn-infecting yeasts (Lu *et al.* 1997; Lu *et al.* 1998). *Candida* spp. represented the greatest number of isolates and *Candida sake* I and II was the most common (two-thirds of isolates). *Candida sake* was found to be the most common in water and sediments in prawn ponds.

15.5.1.5 Metazoal parasites

Reports of metazoan parasites in cultured *M. rosenbergii* are rare. Most reports concern the occurrence of parasitic isopods and trematode worms in natural populations of other *Macrobrachium* species.

Macrobrachium spp. are definitive hosts for the bopyrid isopod *Probopyrus* (Truesdale & Mermilliod 1977; Ordinetz-Collart 1990; Román-Contreras 1993). The asymmetrically shaped female bopyrid is found attached to the branchiostegite wall within the gill chamber, and feeds on the host haemolymph by perforating the prawn integument with the aid of the mandibles. The symmetric free-living dwarf males are found associated with the parasitic female. The presence of the parasite in the gill chamber usually induces a visible swelling and discoloration on the branchiostegite (Truesdale & Mermilliod 1977). Reported effects of bopyrid parasitism on the host are castration (interruption of vitellogenesis) in female prawns and morphological alteration of secondary sexual characters in male prawns (Beck 1980; Schuldt & Rodrígues-Capítulo 1985; Ordinetz-Collart 1990).

Freshwater prawns may serve as intermediate hosts for digenetic microphallid trematode worms. Encysted metacercaria have been reported in the body musculature of *M. ohione* (Bridgman 1969; Heard & Overstreet 1983) and *M. australiensis* (Shimazu & Pearson 1991). Nash (1989) reported the only known trematode parasitism in *M. rosenbergii* musculature and described the formation of a haemocytic capsule surrounding the parasite as a result of the host defence response. Velasquez (1980) reported the occurrence of mammals and humans infected by a macrophallid of *Macrobrachium* sp. in the Philippines. Soh *et al.* (1964) reported that in Korea, in addition to the usual freshwater crab host, *Macrobrachium nipponense* may act as a host for the Asian lung fluke, *Paragonimus westermani*. In a 4-year study wherein 7000 individual *M. nipponense* were examined from an area endemic for the fluke, no lung flukes were found, in comparison to 62% prevalence in freshwater crabs from the same location. Because the Korean study found only 0.14% infections in the prawns, Lu & Huang (1971) concluded that the results indicated an unimportant role for prawn transmission of the lung fluke.

15.5.2 Non-infectious diseases

The following section deals with fouling and environmental diseases. Nutritional inadequacies and imbalances are discussed in Chapter 13 (see also section 15.5.3.2), while the influence of various toxicants are presented in Chapter 14.

15.5.2.1 Fouling by epibionts

The general body surface of the prawn can serve as a substrate for epibionts, such as filamentous bacteria, single or colonial protozoans and filamentous algae. These organisms are non-invasive and their presence on the cuticle surface does not trigger the activation of the proPO system, unless a localised mechanical trauma is also present. Shedding of the exoskeleton during ecdysis temporarily frees the prawn from these fouling micro-organisms. Large animals and blue claw males, which moult less often, are frequently seen with excessive burdens of epibionts.

The presence of epibionts, nonetheless, can be deleterious. Fouling by various micro-organisms can provoke natatory and feeding impairments during the larval and post-larval phases. Heavy infestation on the gills by ciliate protozoans or filamentous bacteria can significantly reduce the efficiency of gas exchange, and may cause death in juvenile or adult prawns by 'suffocation' even when DO_2 levels are not critical.

Heavy infestation of filamentous algae over the body surface of animals reared in clear ponds, or protozoans and miscellaneous microbes in other rearing systems, may also diminish the market value of prawns by rendering an aesthetically unfavourable appearance to the product. Infestation by filamentous algae has been observed in grow-out ponds with high transparency (above 40 cm). Heavy fouling by the chlorophyte *Oedogonium* and the cyanophyte *Lyngbya* can cause lethargic behaviour in *M. rosenbergii* (Smith *et al.* 1979). Maintenance of adequate water transparency in the ponds diminishes light penetration and alleviates algal fouling.

The most common protozoans found in *Macrobrachium* culture are the peritrich ciliates *Zoothamnium*, *Epistylis*, *Vorticella*, *Opercularia*, *Vaginicola*, *Cothurnia* and *Lagenophrys*, and the suctorians *Acineta, Podophrya, Tokophrya* and *Ephelota* (Johnson 1982; Camacho & Chinchilla 1989a). An illustrated key to the epibiont ciliates of decapod crustaceans can be found in Camacho & Chinchilla (1989b).

Protozoan epibionts are epicommensals, filtering or capturing their food from the surroundings. Therefore, it is no surprise that they are commonly found in association with the feeding appendages and in the branchial chamber. In the branchial chamber, epibionts (the colonial filamentous bacteria *Leucothrix* included) take advantage of the protective shelter provided by the lateral folds of the carapace which cover the gills (the branchiostegites), as well as the constant water movement in the gill chamber which is induced by the scaphogantite, or gill blade. This water movement constantly provides suspended food particles as well as oxygen to the epibionts.

Considering the feeding habits of epibiont protozoans, the occurrence of a heavy infestation is, thus, a good indication of high levels of organic matter in the water (Johnson 1982). Preventive measures should therefore include feeding adjustment or increased water replacement in larval tanks or grow-out ponds.

Chemical treatments suggested for the control of epibiont protozoans in small systems include the use of formalin, either as a 24-hour immersion bath with 40 to 50 p.p.m. formalin solution and constant aeration (Roegge *et al.* 1977) or 50 to 125 p.p.m. formalin for 12 h (Brock 1993), a 2% solution of tincture of Merthiolate® for 20 min (Colorni 1985), and a 1-minute dip in 2.0 p.p.t. acetic acid. Control of

Leucothrix can be performed with chelated copper (algicide) solutions which provide 0.1 mg of copper/L for 4 to 6 h using an immersion bath technique (Brock 1993).

15.5.2.2 Environmental diseases

Macrobrachium rosenbergii specimens affected by idiopathic muscle necrosis (IMN) show a whitish colour in the striated muscle of the tail and appendages (Brock 1993). This discoloration results from the lysis of the muscle cells, which is followed by necrosis (Nash *et al*. 1987). At the chronic stage of the disease, the necrotic affected area may increase in size and acquire a reddish colour, similar to cooked shrimp, due to decomposition of the muscle tissue. Secondary pathogens (bacteria and the fungus *Fusarium*) have been found associated with IMN. All *M. rosenbergii* life stages are susceptible to IMN. Prawns suffering from chronic IMN do not survive and mortality rates in culture populations are reported to vary from insignificant to 100% (Brock 1993).

The development of the disease appears to be associated with poor management. Idiopathic muscle necrosis has been observed in populations submitted to high stocking rates and handling stress, as well as to stressful environmental conditions, such as low DO_2 level, and salinity and temperature fluctuations (Tonguthai 1992; Brock 1993; New 1995). The obvious preventive measures are the application of good husbandry to avoid IMN-inducing stressors.

15.5.3 Diseases and syndromes of undetermined aetiology

15.5.3.1 Mid-cycle disease

Mid-cycle disease (MCD) is an important disease in *M. rosenbergii* hatcheries. Although the implication of many pathogens, toxic compounds or pesticides have been suggested, a precise cause remains unknown.

The name MCD derives from the developmental pattern of the disease once it establishes in the larval population. Characteristically, a heavy daily loss of larvae is more pronounced in the middle of the larval rearing period. This usually occurs by days 15 to 22 when zoea are at stage VI–VII (Akita *et al.* 1981; Brock 1993). An earlier 'incubation period' can be recognised, usually starting at day 10 and lasting for 4 to 6 days (Akita *et al.* 1981). Gross signs displayed by MCD-afflicted larvae during the incubation period include lethargy, a spiralling swimming pattern, reduced growth rate and consumption of *Artemia*, and bluish-grey colour of the body (Akita *et al.* 1981). The mortality pattern, atrophy of the hepatopancreas and presence of bacterial masses (Gram-negative coccobacilli) in the gut lumen are indicative of MCD (Brock 1993).

The occurrence of MCD has been reported in Hawaii (Akita *et al.* 1981; Brock 1983, 1993), Malaysia (Anderson *et al.* 1990b) and Brazil (Lombardi & Lobão 1991; Bueno & Gastelú 1998). Hatcheries that practise equipment cleaning, disinfection and dry-out between cycles and utilise good sanitary practice have minimal problems with MCD (Brock 1993). Should an MCD epizootic demand a full clean-up, the complete destruction of the afflicted population and a thorough disinfection of the hatchery installation should be considered. Mid-cycle disease is probably a disease of multiple aetiology.

15.5.3.2 Exuvia entrapment disease

The exuvia entrapment disease (EED), which is also known as moult death syndrome (MDS) or metamorphosis moult mortality syndrome, is characterised by the entrapment of the larvae in the old exoskeleton (exuvia) during ecdysis. This primarily occurs late in the period of larval rearing, especially at the metamorphic moult to the post-larval stage (Brock 1993). Typically, the time of development to the post-larval stage is delayed in EED (Brock 1993). Affected larvae frequently show localised deformities due to the mechanical pressure of the old cuticle on the newly formed one (Bueno & Gastelú 1998). Mortalities occur during unsuccessful attempts by larvae to shed the exuvia, and may reach 80% by the time of metamorphosis (Brock 1993). An exuviae entrapment-like disease has also been associated with mass mortality of *M. malcolmsonii* in hatchery tanks (Kanaujia *et al.* 1998).

The cause of EED is not known and many hypotheses have been put forth. The idea of multiple causes is plausible. Preventive strategies should include use of a new water supply of more suitable quality, and dietary enrichments (Brock 1993). Juvenile and adult prawns have also been observed to exhibit similar symptoms (M. New & W. Valenti, pers. comm. 1999) and the cause is thought to be primarily dietary. The moulting process creates severe physiological stress, and it is at this time that underlying problems reveal themselves.

15.6 Final considerations

Neglect and matters of economy impede expansion in our knowledge of prawn health. Currently, a limited number of observations and incidents comprise our general knowledge of freshwater prawn disease. Reluctantly or not we continue to freely apply concepts to prawn health that have little empirical bases with the group. Knowledge of the stress phenomenon, for example, is little known for any crustacean group. Within the realm of health study, there are several areas that critically need attention:

- *Pathogenesis*: As a recurring pattern of disease is recognised and given an adequate definition, it is essential that a reliable pathogenesis be developed. A concurrent establishment of a correlative epidemiology can thus support meaningful management.
- *Resistance*: *Macrobrachium rosenbergii* is an excellent candidate for genetic improvement of cultured stocks. Through a carefully controlled programme it should be possible to obtain specific pathogen resistant (SPR) stocks in a similar way as has already been done for penaeid shrimp (Bédier *et al*. 1998). The use of immunostimulants may have potential in prawn culture. Promising results have been obtained for the enhancement of non-specific disease resistance by using an immunostimulant with penaeid shrimp (Sung *et al*. 1996; Song *et al*. 1997). A better definition is required for the reasons why environmental factors overwhelm the compensation potential of prawns and thus predispose disease. Sufficient measures would allow producers to predict outcome according to different system types and animal developmental stage.
- *Quality of hatchery water*: The effects on prawns of parameters such as oxygen and nitrogen waste products in hatchery tank water is quite well known but the effects of the extracellular products (enzymes), which must certainly be present in measurable quantities in such water, is relatively unknown. The use of probiotics and other microbial management measures have strong potential for improving hatchery yields.
- *Management tools and practices*: Hatchery sterilisation (disinfection) strategies require much improvement. Hatchery fumigation and shock chlorination, for example, require a prolonged post-application venting that makes the facility an essentially open system. Producers need to be equipped with a broader array of health products that provide standard methods of measurement for on-farm evaluations. Commercial availability of reliable, user-friendly products will assure widespread application.
- *Training*: Availability of training programmes in prawn health and diagnostic methods would greatly aid the development of prawn culture. On this point, the cross training of diagnosticians and producers would bring more rapid advances in competence, particularly among the former. Histopathologists, with sound knowledge on and experience with prawn diseases, are absent or rare in most countries where *Macrobrachium* farming is practised.

It is certain that advances in nutrition, disease control and general system management will improve performance in freshwater prawn culture. Average survival percentage – so economically important in grow-out – would thereby continue to approach that found among other types of aquaculture. Fortunately, the considerable increase in the economic importance of crustacean aquaculture generally will be accompanied by an expansion in service and research laboratories, and in the numbers of people who are competent to generate, interpret and report data relevant to health management.

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16

The Biology and Management of Size Variation

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The wide range of sizes that develops in prawn populations and particularly in the males is a very typical characteristic of *Macrobrachium rosenbergii* culture and a major obstacle to increased profitability. Prawn prices are size dependent and those below a minimal size are often used as bait for fish or are discarded by the growers. Male populations are bi- or multi-modal and positively skewed, comprising a large fraction of small, unmarketable individuals and a fraction of large prawns. Early workers recognised obvious but only superficial parallels between the prawn growth pattern and that of the common carp, with its rapidly growing shoot carp or tobi-koi (Nakamura & Kasahara 1957). Removal of the shoot carp and of the large prawns leads to a rapid compensatory growth of the smaller animals. The prawn growth pattern is, however, much more complicated than that of the common carp. Prawn size variation actually reflects a complex population structure, composed of three sexually mature male morphotypes (small male, orange claw male and blue claw male), which differ in their morphology, physiology and behaviour, and transform from one morphotype into another. Recent research has revealed that prawn growth is affected by a very early determination of the male developmental pathway, based on the juvenile relative size ranking. Prawn growth regulation – suppression as well as enhancement – is achieved mainly by means of social interactions among individuals.

In the tropics, with the traditional all-year culture system, size variation is only partly and inefficiently managed by the selective removal of large individuals, and the industry does not realise its full potential. In the temperate zone, prawn culture has not yet achieved true economic viability (see Chapters 11 and 20). It became obvious that a major limiting factor for prawn culture was the prawn growth pattern.

Many studies, including numerous MSc and PhD dissertations related directly and indirectly to prawn size variation, have been published. Research areas were extremely diverse (morphology, anatomy, physiology, biochemistry, ecology and social behaviour). In this review we have assembled pieces of information related to size variation, in order to try to solve the puzzle of the prawn's complex growth pattern and to evaluate the strategies for its efficient management.

16.1 Male morphotypes

A general account of the morphology of *M. rosenbergii* is provided in Chapter 3. This section concentrates on the morphological characteristics of males.

16.1.1 External morphology

Three distinct male morphotypes and several intermediate forms have been described for sexually mature *M. rosenbergii* (Plate 4, facing p. 220). The blue claw (BC) male, characterised by its extremely long claws, was the only male type of this species to be described during the early studies of its biology (Rao 1965; Ling 1969b). A second type of male, a small runt with small claws was first described among pond populations (Fujimura & Okamoto 1972). These stunted small males (SM), were initially differentiated from the younger juveniles by their greater age. The third male type, the orange claw (OC) male, was described for the first time by Sandifer & Smith (1977), who emphasised the golden colour of its claws and their length: 30 to 70% shorter than those of blue claw males. Differentiation among the three male morphotypes in the initial studies on the structure of pond populations was based mainly on size, claw colour and the ratio of claw length to total length (Brody *et al.* 1980; Ra'anan 1982; Cohen & Ra'anan 1983).

Kuris *et al.* (1987) provided an operational definition of male morphotypes by means of allometric growth techniques supplemented with observations of colour and spination. Transition from the SM to the OC morphotype was gradual, and a recognisable intermediate form, the weak orange claw (WOC), was identified and differentiated from the SM and the strong orange claw (SOC). Mainly, the relationship between the distal joints of the claw (i.e. propodus and carpus) and carapace length, used as a reference dimension, were analysed in order to study relative growth of the different male morphotypes. All four male morphotypes exhibited linear and highly correlated associations of the logarithmically transformed relationship of propodus and carpus length to carapace length. However, each morphotype had a different combination of slope and intercept, which enabled a clear differentiation to be made among the morphotypes (Fig. 16.1). Spination was found to be a reliable discriminator between BC and OC males: BC male spines are longer and more robust than those of OC males, and add, on average, 7% to the width of the propodus. Spine orientation is also different; BC male spines point distally at an angle of 60 to 75° while those of the OC males form a more acute angle of 30 to 45°. Sagi & Ra'anan (1988) defined an additional intermediate form – the transforming orange claw (TOC) – representing the last stage of the SOC male before it transforms into the BC male.

16.1.2 Internal morphology and physiology

Most comparative studies on the anatomy and physiology of the male morphotypes focused on the reproductive system, because different reproductive strategies are adopted by different male morphotypes (Telecky 1982, 1984; Ra'anan & Sagi 1985; Sagi 1990). The male reproductive system in *M. rosenbergii* consists of a pair of testes, vasa deferentia, ejaculatory ampullae and genital pores.

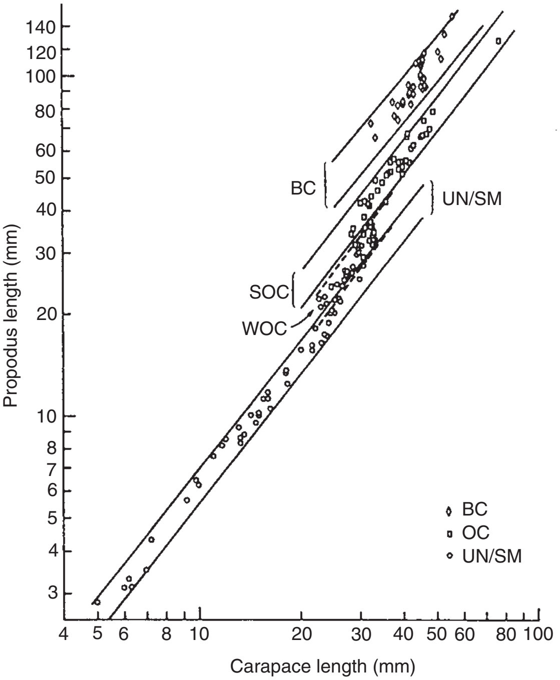

Fig. 16.1 Relationship between log carapace length and log propodus length for male *Macrobrachium rosenbergii* morphotypes. (Source: from Kuris *et al.*, 1987.)

Key: BC = blue claw; SOC = strong orange claw; WOC = weak orange claw; SM = small male; UN = undifferentiated, juvenile male without appendix masculina. Solid lines are the upper and lower 90% predicted confidence limits of each male morphotype.

The testes are whitish paired structures united at their anterior ends which lie mid-dorsally in the cephalothorax and are composed of numerous branching spermatogenic lobules. The spermatogenic zone is located along the wall of each lobule and its lumen is filled with developing and mature spermatozoa which are non-flagellated, non-motile and resemble everted umbrellas (Nagamine *et al.* 1980; Sandifer & Lynn 1980; Lynn & Clark 1983). The vasa deferentia are two symmetrical elongated tubes which consist of a short proximal portion attached to the testes, a long convoluted portion and a straight distal portion ending with the ejaculatory ampullae. This structure consists of an enlargement of the vas deferens encircled by a thick layer of transverse and longitudinal muscles, and opening at the base of the fifth pereiopod. The walls of the vas deferens secrete both a basophilic protective matrix and an eosinophilic, adhesive, gelatinous matrix which, together with the sperm, compose the spermatophore that is extruded at mating by the contraction of the muscles of the ejaculatory ampullae (Chow *et al.* 1982). Attached to each ampulla is the androgenic gland (see section 16.3.2).

Detailed comparative studies of the structure of the reproductive system, testicular sperm production and storage have been carried out on the three major male morphotypes and two intermediate forms: the WOC and the TOC (Sagi & Ra'anan 1988; Sagi *et al.* 1988). The following parameters were compared: gonado-somatic index, length of the reproductive system relative to the carapace length, histology of the testes, *in vitro* sperm release during a 24-hour period of incubation and *in vitro* testicular [^{3}H]-thymidine incorporation, which represents DNA synthesis. Similarly to SMs of other species which use a sneak mating strategy (e.g. fish, Warner & Robertson 1978; Warner & Le Juenne 1985), small *M. rosenbergii* males had a relatively large reproductive system (Sagi & Ra'anan 1988). The testes of SMs were described as producers and storers of sperm. The high rate of spermatogenesis in the SM testes was revealed by the prominent multi-layered spermatogenic zone in their spermatogenic lobules and the high rate of [^{3}H]-thymidine incorporation. The sperm storage function of the gonad was revealed by both the presence of mature spermatozoa in the spermatogenic lobules lumen and the high rate of *in vitro* sperm release. The BC male testis serves mainly as a sperm reservoir; its low spermatogenic activity was reflected in the low rate of [^{3}H]-thymidine incorporation and the almost complete lack of a spermatogenic layer in its testes. The three OC male forms (WOC, SOC and TOC) represent a series of gradual changes in gonadal spermatogenic activity, in which several parallel processes take place. First, the abundance of mature sperm found in the SM testes declines, and the sperm almost disappears in the early OC stages. Concomitantly, the rate of spermatocyte production increases when the SM moults into the OC phase. An additional component of this complex process is moulting. The OC phase is characterised by frequent moulting, a process which has been shown to be strongly correlated with spermatogenesis (i.e. with [^{3}H]-thymidine incorporation – Sagi *et al.* 1991). Orange claw males in the premoult phase had a rate of [^{3}H]-thymidine incorporation about four times higher than that of OC males in the intermoult phase. In the more advanced OC male phases, the spermatogenic zone becomes thinner as the testicular cylinders become filled with spermatocytes (Sagi *et al.* 1988; Sagi 1990).

Since the male morphotypes differ in their growth rates (Ra'anan & Cohen 1985), comparative studies have been carried out on the relative weights of their midgut glands – the hepatopancreas (Sagi & Ra'anan 1988). These glands have been described as playing a major role in food assimilation (Yonge 1924; Dall & Moriarty 1983) and mobilisation of energy during moulting (Travis 1955, 1957; Skinner 1985) and, therefore, their relative size was suggested by Sagi & Ra'anan (1988) also to reflect energy spent on somatic growth. The weight of the midgut glands relative to body weight was found to be significantly larger in the rapidly growing SOC male than in all other morphotypes. The slow-growing SMs and BC males had the lowest relative midgut gland weight, while the WOC and the TOC males had intermediate values. These results were recently confirmed by Sureshkumar & Kurup (1999).

16.1.3 Behaviour

16.1.3.1 Agonistic behaviour

In early Indian studies, *M. rosenbergii* males were described as being very aggressive, and fighting with their second pair of claws while competing for receptive females (John 1957; Rao 1965). A general description of aggressive group interactions was provided by Segal & Roe (1975), in a study that emphasised cannibalism and growth. The first quantitative study on prawn aggressive behaviour, including the description of four aggressive acts, was provided by Peebles (1979b) in a study on competition for shelters. Relative size, prior residence and the length of time rivals had been paired were found to play important roles in the outcome of contests. In a series of elegant studies, using a procedure he had developed for determining the moult state, Peebles (1978, 1979a,b, 1980) demonstrated the effect of moult state on prawn aggressive interactions, distribution and survival. Prawns in late premoult and early postmoult suffered from body injury and death because of cannibalism by equally sized prawns in the intermoult state. Prawns were found to segregate according to moult state in both the field and the laboratory. The occupation of shallow *versus* deep areas of a testing tank by soft- and hard-shelled prawns, respectively, was found to be the result of competition and not of a change in habitat preference with the moult state.

Initial descriptions of the aggressive behaviour of the various male morphotypes were of a general nature. Sandifer & Smith (1977), in their first description of the OC male morphotype, stated that it appeared less aggressive than the BC male. In their study of male alternative mating strategies, Ra'anan & Sagi (1985) concluded that BC males were aggressive, dominant and territorial, OC males were aggressive, sub-dominant and non-territorial and SM males were submissive and non-territorial. Most of these early findings were later corroborated in detailed studies of male agonistic behaviour and hierarchy formation (Karplus & Harpaz 1990; Barki *et al*. 1991a,b, 1992, 1997).

Intra-morphotypic agonistic interactions have been studied by analysing the structure of contests between prawns matched in size, all in the intermoult states (Barki *et al*. 1991b). Eighteen different agonistic acts were described and classified into indicators of dominance and subordinance, following the application of cluster analysis. The fighting behaviour of the three male morphotypes differed, following the direction of the morphotypic developmental pathway (i.e. from SM through OC to BC). In accordance with this trend there was a decrease in the use of physical contact, and also fewer displays of claw position and movement in the repertoire of SM than in those of OC and BC. It has been suggested that the above differences among the morphotypes reflect a tendency of shifting to more ritualised interactions, from SM through OC to BC, correlated with the increases in claw size and in the chance of severe injuries inflicted by the claws.

The formation of dominance hierarchies has been studied in groups consisting of the three male morphotypes, each represented by two males of similar size, with BC and OC males matched according to carapace size (Barki *et al*. 1991a). Prawns formed a morphotype-related linear dominance hierarchy in which BC males were dominant over OC males which, in turn, were dominant over SM. Stabilisation of the hierarchy over a period of 3 days was evident from the reductions in the number of agonistic interactions and in their intensity. The three male morphotypes differed in the extent to which they were involved in agonistic interactions, and in the nature of these interactions. The highest proportion of all interactions were intra-morphotypic, involving BC males. The proportion of inter-morphotypic interactions involving BC males was lower, decreasing from OC to SM. Interactions between BC males were of a more ritualised nature, with less physical contact. Those between BC and OC males involved more physical contact, while in their encounters with SMs, BC males used more threat displays and mere approaches.

The effects of body and claw size and male morphotype on the formation of dominance hierarchies were studied in mixed groups of BC and OC males, each represented by prawns in three size categories. Blue claw males dominated OC males, irrespective of body size; in some cases an advantage of 8% in claw length overrode a disadvantage of 80% in BC weight, compared with OC (Barki *et al*. 1992). However, when BC and OC males were matched according to claw size, the probability of the two morphotypes to win was even. In this species, cheliped size appears to be a single overriding factor on which assessment of fighting ability is based (Barki *et al*. 1997). Schmalbach *et al*. (1994), in a study describing a new tagging method for *M. rosenbergii*, emphasised the importance of the sum of the chelae lengths in establishing dominance.

Behavioural interactions among male prawns have been studied under semi-natural conditions in an earthen pond with clearwater (Karplus & Harpaz 1990). Agonistic interactions among prawns, 3 and 4 days after their introduction into the pond, were brief, usually consisting of a single act performed by one prawn, and followed by the retreat of its adversaries. A morphotype-related dominance hierarchy was formed, with BC males ranked above OC males. The dominance hierarchy seemed to regulate priority of access to preferred areas (e.g. shaded protected crevices). As soon as the holder of a preferred spot was supplanted, all aggressive interactions ceased. The results of this study must be evaluated cautiously since it lacked replicates, and individually tagged prawns were studied for a short period of time. The prawns in this study did not exhibit territoriality, if a territory is defined as a fixed exclusive area defended to keep intruders out (Brown & Orians 1970). Although the use of radio transmitters revealed a limited home range for large males in ponds (Peebles 1979a), there is, so far, no evidence for territoriality in this species, as defined by Brown & Orians (1970). Laboratory studies did indicate eviction of competitors, but only from the vicinity of a limiting resource – shelter (Segal & Roe 1975), food (Barki *et al.* 1992) and a receptive female (Telecky 1982). Field studies combining the tracking of the movements of individually tagged prawns and their social interactions over extended periods of time are needed finally to resolve the question of territoriality in this species, as well as that of the occurrence of stable dominance hierarchies in wild-ranging animals.

16.1.3.2 Reproductive behaviour

Early studies on the reproductive behaviour of *M. rosenbergii* were carried out by staging encounters between males and females, after a pre-mating moult (Ling & Merican 1961; Rao 1965; Ling 1969b; Chow *et al.* 1982). This approach overlooked the important mate search phase by females prior to their pre-mating moult, early pair-formation and the resulting rapid fertilisation following the female pre-mating moult. Studies on nocturnal motor activity of females in ponds, with the aid of radio transmitters, revealed an increase in the distance covered by females as they approached the pre-mating moult, probably reflecting the search for a suitable prospective mate (Peebles 1979a). Night-time observations in earthen ponds indicated that sexually ripe females oriented in and around breeding depressions constructed by large males (Smith & Sandifer 1979a). Observations carried out in aquaria over a period of several weeks on several groups of individually tagged females, each with a large BC male, revealed consistent early pair-formation. Females approached a male 2 to 3 days prior to the pre-mating moult, first being chased away but later, after several hours of persistence, being allowed to remain in the male vicinity. About 24 h prior to the pre-mating moult the female would already be totally accepted by the male, positioned below it or between its long second pair of claws (I. Karplus, personal observation). An earlier account of a BC male guarding a female prior to her pre-mating moult was given by Sagi & Ra'anan (1985). As a result of the early pair bond between the female in the pre-mating moult state and the male, fertilisation occurs several minutes to 30 min after moulting (I. Karplus, personal observation). Earlier studies have reported fertilisation to occur 8 to 12 h (Ling & Merican 1961; Rao 1965), 3 to 6 h (Ling 1969b) and 1.2 to 21.8 h (Chow *et al.* 1982) after moulting. These females were indeed receptive, but the time of fertilisation was much determined by when they were paired with the male by the researcher. The reproductive potentials of the various male morphotypes were evaluated by pairing a single male with a single female after the pre-mating moult, thus eliminating the interference of groups of eager-to-mate males. All three male morphotypes had similarly high rates of fertilising receptive females. Despite the fact that the spermatophores of SMs are about half the size of those of BC males, the number of viable embryos sired by the three male morphotypes was dependent only on the female size. None of the males of any of the three morphotypes attacked or injured the females that they had just fertilised (S. Zafrir, pers. comm. 1999).

Mating behaviour in the three male morphotypes has been described. All early accounts of the reproductive behaviour of *M. rosenbergii* dealt with the mating of BC males; this is revealed by the figures accompanying these descriptions (Rao 1965; Chow *et al.* 1982) and by the emphasis on the very long claws of the males (Ling & Merican 1961; Ling 1969b). Chow *et al.* (1982) divided the mating behaviour of BC males into four phases: contact, seizure, mounting and copulation. Following mating the female is guarded for 2 to 3 days by the male, but during that time the female gradually moves away from his close vicinity. The female leaves the male completely when her exoskeleton is hard enough to withstand attacks by conspecifics (I. Karplus, personal observation).

Orange claw males were described as capable of fertilising females but having an incomplete sexual behaviour, never grooming or protecting a female. Actual severe or fatal injuries (18.7%) were reported, following the pairing of a female with several OC males, prior to her pre-mating moult (Ra'anan & Sagi 1985). The mating behaviour of the OC morphotype, as studied by pairing single males with a female, following her pre-mating moult, revealed their behaviour to be more variable and lengthier than that of BC males; it completely lacked the female-guarding previously described. However, no damage to females was inflicted by OC males (S. Zafrir, pers. comm. 1999). Differences between studies in reports of mortality and injury may be due to differences in the female moult state and in the numbers of males involved.

Small males have been described as mating with females by sneaking between a receptive female and her guarding BC male (Telecky 1982, 1984; Sagi 1984; Ra'anan & Sagi 1985). Small males were described as probing the female reproductive state by moving from one side of the female, over her back to the other side and finally slipping their abdomen beneath her to apply their spermatophore. Following this act, the SM rapidly retreated before the return of the BC male (Telecky 1982). In a recent study, only SMs but not BC or OC males were found to be chemically attracted to females shortly after their pre-mating moult (Thomas 1998).

Male competition and female mate choice both modify the actual rates of female fertilisation by the different male morphotypes, despite their similar reproductive potentials. Exposing groups of three OC males to a female prior to her pre-mating moult in the presence of a BC male with its gonopores plugged (preventing female fertilisation) resulted in the BC guarding the female and a low fertilisation rate of 20% by the OC males. Mating success of OC males in both natural and pond populations is probably very low (Ra'anan & Sagi 1985).

One of the most elegant studies carried out on male alternative reproductive strategies was that of Telecky (1982, 1984), which took advantage of the polymorphism of the glutamate-oxaloacetate-transaminase (GOT) locus described in the Hawaiian Anuenue strain of *M. rosenbergii* (Malecha 1977). Telecky constructed two populations of runts (SM) and bulls (BC) at a ratio of 2:1. The SM and BC males differed in their GOT genotype. The reproductive success of the SMs could be evaluated by analysing a sample of the eggs of the berried females for their GOT genotype, as determined by gel-electrophoresis. Successful SM mating rates of 18.8 and 30.7% were described in the two populations. The higher success rate of SMs in one of the populations was suggested to result from the time-lag to full establishment of two newly introduced BC males that replaced dead ones. On the basis of 11 observed sneak mating attempts Telecky (1982) suggested that the rate of success depends on the number of runts involved. A single runt has no chance to gain access to a receptive female guarded by a BC male; at least three runts are necessary to achieve copulatory access to females. While the bull is chasing away some of the runts, the female remains unprotected and the opportunity for sneak mating is formed. A relatively higher fertilisation rate (39%) of females by SMs in the presence of a BC male with its gonopores plugged was reported by Ra'anan & Sagi (1985). The higher rate of mating success of SMs could have been due to a higher SM to BC ratio of 5:1, compared with the 2:1 ratio in Telecky's study, and to the inability of the BC male in the latter study to fertilise females. Occasionally following their pre-mating moult, females were collected from earthen ponds with several spermatophores attached to their sperm receptacle. Nothing is known, so far, of sperm competition in this species.

Few studies have so far addressed the question of mate choice by *M. rosenbergii* females. Females 24 h prior to the pre-mating moult, and while still receptive following this moult, preferred BC males to OC males and SMs. Females tested in large circular pools with the three males confined inside wire cages spent much more time in the vicinity of the BC males as compared to the other two morphotypes (S. Zafrir, pers. comm. 1999). In a recent study, females shortly after the pre-mating moult were found to be chemically attracted to BC males but not to OC males and SMs (Thomas 1998). In another study, females in the intermoult state and 24 h prior to the pre-mating moult initiated aggressive interactions with single OC males and SMs but not with BC males (S. Zafrir, pers. comm. 1999). Following the pre-mating moult and in the absence of a choice among the male morphotypes, females were not aggressive with any of the morphotypes and co-operated during mating with each of them. Females stretched their bodies and extended their claws while being turned by BC and OC males and lay on their side to facilitate fertilisation by SM males. A female which does not mate following her pre-mating moult loses all her eggs within a short period of time, because of lack of fertilisation. In the absence of the preferred BC male, females are not choosy and are better off mating with any available male, irrespective of its morphotype, than losing all their eggs.

16.2 Structure of mature populations

16.2.1 Size distribution

Fujimura & Okamoto (1972) were the first to present size frequency distribution histograms of male and female prawns grown in earthen ponds in Hawaii. They emphasised the uniform normal size distribution of females and the bi-modal size distribution of males, whose population consists of a group of stunted 'bachelors' (runts), smaller in size than the females, and bulls which were larger than the females (Fig. 16.2).

Mature prawn populations were studied mostly in temperate zones (South Carolina, Florida, Mississippi and Israel), since all ponds are invariably drained at the end of the limited grow-out season in these areas. Size composition of the harvested population is crucial for the viability of prawn culture, since prawn prices are size dependent. The harvested populations usually represented the undisturbed populations, since no or only few selective harvests were carried out. Smith *et al.* (1978, 1982) were the first to study the effects of various variables on prawn population structure in earthen ponds; in their studies in South Carolina they tested for the effects of density, duration of grow-out period and size of prawns at stocking on population structure. Male and female prawns exhibited distinctly different size distribution patterns. Females exhibited uni-modal and more or less normal distributions over a fairly narrow range, while the male population exhibited markedly skewed bi- or multi-modal distributions over a comparatively broad size range (the standard deviation of the mean weight of males was three times larger than that of females). These studies corroborated and extended the findings of Fujimura & Okamoto (1972) on sex-linked size distribution patterns under a wide range of densities.

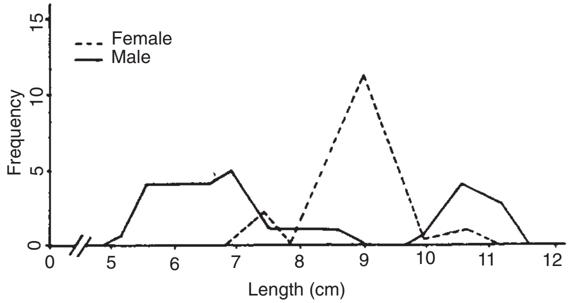

Fig. 16.2 Length frequency distribution of male and female *Macrobrachium rosenbergii* showing the bi-modal distribution of the 'bull-runt' phenomenon. (Source: from Fujimura & Okamoto, 1972.)

Numerous studies have clearly demonstrated a negative correlation between prawn stocking density and prawn growth rate and mean size at harvest, both in polyculture with fish (Cohen *et al.* 1983; Wohlfarth *et al.* 1985; Karplus *et al.* 1986a) and in prawn monoculture (Sandifer & Smith 1975; Willis & Berrigan 1977; Brody *et al.* 1980; Smith *et al.* 1981; D'Abramo *et al.* 1989; Valenti *et al.* 1993; Sampaio & Valenti 1996; Siddiqui *et al.* 1997).

16.2.2 Sex ratio

Higher proportions of females than males were found in prawn populations in a number of studies when prawns were raised in different geographical areas at a wide range of densities, in earthen ponds and in tanks (Willis & Berrigan 1977; Smith *et al.* 1978, 1980, 1981, 1982; Sandifer *et al.* 1982; D'Abramo *et al.* 1986; Karplus *et al.* 1986a; Lin & Boonyaratpalin 1988; Siddiqui *et al.* 1995, 1997). Three different mechanisms have been suggested by Smith *et al.* (1978) as possibly regulating the prevalence of females in prawn populations. Firstly, environmental conditions may affect sex determination and favour the development of females. Secondly, females may already outnumber males at stocking. Thirdly, selective male mortality may occur. Sagi & Cohen (1990) reported an equal sex balance (determined as soon as sex could be identified) in the progeny of two normal matings, whereas Malecha *et al.* (1992) reported a higher frequency of females in the progeny of five crosses between normal males and females. The difference in the results of these two studies has been attributed to environmental influences in the latter study. The selective male mortality hypothesis seems highly plausible under crowded pond culture conditions. Prawns are known to be vulnerable to limb damage and cannibalism during moulting, even under conditions of excess food (Segal & Roe 1975; Peebles 1978). Females, unlike males, can avoid these hazards, at least during the pre-mating moult, by seeking refuge between the claws of BC males before and after ecdysis (see section 16.1.3.2).

16.2.3 Male morphotypes

Closer examination of harvested mature prawn populations has revealed that they are composed of three distinct male morphotypes (SM, OC and BC) which represent the normal male developmental pathway from SM to BC via OC (Ra'anan 1982; Ra'anan & Cohen 1985). Early studies on the effect of prawn density on male morphotypes, carried out over a relatively narrow range (0.5–1.5/m^2), suggested fixed proportions of male morphotypes (SM : OC : BC = 5 : 4 : 1) irrespective of prawn density (Cohen & Ra'anan 1983; Ra'anan & Cohen 1985). Subsequent studies (Karplus *et al.* 1986a), covering a wider density range (1–4/m^2), revealed that the proportions of the male morphotypes change significantly with density (Fig. 16.3). The frequency of SMs almost doubled as the stocking density increased from 1 to 4 prawns/m^2 (33 and 57%, respectively), while the frequency of the large BC males showed the reverse trend, namely decreasing by half from the low to the high stocking density (20 and 10%, respectively). The possibility that prawn populations had not yet stabilised was ruled out since rates of berried and spent females were similarly high at all densities, indicating the populations to be mature and fully developed. The changes in morphotype frequencies with density reflect increased stunting of prawn populations with increased density. At high densities large fractions of the population are in close contact with BC males, which inhibit their growth (see section 16.4.3). Studies in Mississippi (D'Abramo *et al.*

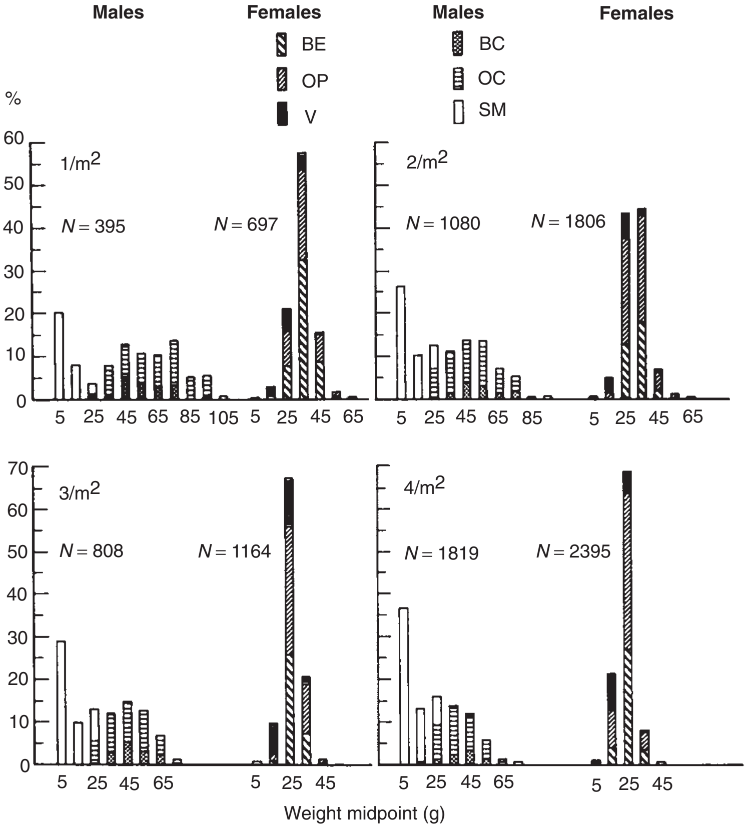

Fig. 16.3 Weight distribution of *Macrobrachium rosenbergii* male morphotypes and female reproductive states raised in earthen ponds at different densities. (Source: after Karplus *et al.*, 1986a.)

Key: BC = blue claw; OC = orange claw; SM = small male; BE = berried female; OP = open brood chamber, spent female; V = virgin female.

1989) covering prawn densities of 4 to 11/m^2 corroborated these findings and extended them to a wider range.

An inverse relationship between prawn density and mean size of the various male morphotypes has been described in prawn populations covering a wide range of stocking densities (Cohen *et al.* 1981, 1983; Karplus *et al.* 1986a; D'Abramo *et al.* 1989; Siddiqui *et al.* 1997). The only male morphotype that showed no effect of density on its mean weight was the SM; at all densities the growth of suppressed SMs was negligible (Cohen *et al.* 1981; Karplus *et al.* 1986a; Siddiqui *et al.* 1997).

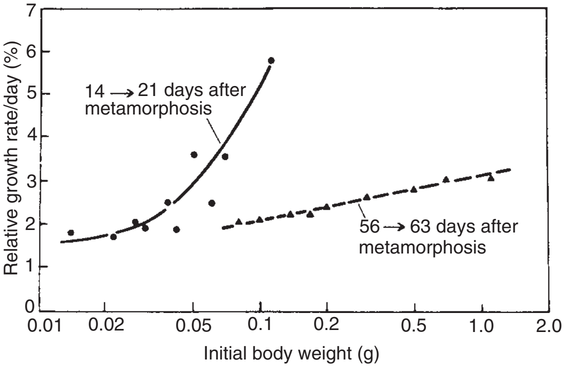

Fig. 16.4 Relation between initial body weight and relative growth rate of juvenile *Macrobrachium rosenbergii* communally reared at two time intervals after metamorphosis. (Source: after Ra'anan & Cohen, 1984b.)

16.3 Ontogeny and development

16.3.1 Development of size variation

Populations of newly metamorphosed postlarvae (PL) have a relatively homogenous size distribution, as reflected in their small variance (mean = 0.009 g; $\sigma^2 = 6.0 \times 10^{-6}$ g; Sandifer & Smith 1975; Malecha *et al.* 1977). Several investigators have presented a general description of the rapid increase in size variation following metamorphosis (Wickins 1972; Forster & Beard 1974; Sandifer & Smith 1975; Segal & Roe 1975; Malecha *et al.* 1977). However, a detailed and focused analysis of the development of juvenile populations, by means of specifically designed experiments was carried out by Ra'anan and her co-workers (Ra'anan 1982, 1983; Ra'anan & Cohen 1984a,b) and subsequently reviewed by Ra'anan & Cohen (1985).

Prawn populations display a disproportionate increase in size variation with time because individual prawns grow at different rates (i.e. they show heterogeneous individual growth – Malecha *et al.* 1981a). Ra'anan & Cohen (1984a,b) monitored large differences among the specific growth rates (Ricker 1975) of marked individuals. The relative growth rates were positively correlated with the initial body weights of juvenile prawns (Fig. 16.4). Two distinct types of juveniles were defined on the basis of their relative growth rates: 'jumpers' and 'laggards'. Jumpers are exceptionally fast-growing individuals that may become up to 15 times larger than the population mode within 60 days after metamorphosis, forming the leading tail of the population. Jumpers within a monitored population of juveniles became evident within 2 weeks after metamorphosis. The largest marked individuals, forming 5% of the population, remained within the leading tail during the entire 60 days of the study. Early in the development of prawn populations the jumpers included equal proportions of males and females. The proportion of jumpers in juvenile populations (defined as individuals larger than the mean by more than 1 s.d.) ranged from 15 to 22%, irrespective of prawn density. Slow-growing prawns (laggards) became apparent only later, about 5 weeks following metamorphosis. It has been suggested that growth suppression in these individuals may depend upon the presence of the larger jumpers (Ra'anan 1983). Jumpers and laggards did not develop under isolated culture conditions indicating the importance of group interactions for their development (Ra'anan & Cohen, 1984b). However, after a specific growth pattern (i.e. fast growing in jumpers or slow growing in laggards) had been established, juvenile prawns continued to show different growth patterns, also when isolated (Ra'anan 1983; Karplus & Hulata 1995).

In order to control for absolute size differences between jumpers and non-jumpers, Ra'anan (1983) raised PL from a single brood at two densities (1 PL/L and 10 PL/L) and obtained jumpers from the high-density population which overlapped in weight with the non-jumpers from the low-density population. Isolated jumpers demonstrated an almost six-fold higher weight increment per moult cycle than non-jumpers, despite similarity in absolute weight. These results clearly indicated the overriding importance of the relative size ranking of the individual within the original population as opposed to absolute weight, as a predictor of growth rate. Jumpers and non-jumpers matched according to size by the above procedure, also behaved differently in a social context. The relative growth rate was significantly higher in jumpers that were raised with non-jumpers than in those raised alone, while the reverse was found for non-jumpers, which grew better alone than when paired with jumpers (Ra'anan 1982; Ra'anan & Cohen 1985). In a complementary study, the effects of social interactions on the moult cycles of jumpers and non-jumpers were investigated (Ra'anan 1983).

Compensatory growth in juveniles was demonstrated by removing the jumpers from a prawn population three times in succession (Ra'anan 1982; Ra'anan & Cohen 1985). The growth rates of the harvested populations were twice as high as that of the control populations. It was suggested that the regeneration of the jumpers' leading tail indicates an inherent capacity for compensatory growth in non-jumpers, which is triggered by a social cue – the removal of jumpers.

The growth of mid-sized prawns removed from a population was tested in a new social environment consisting of different sized prawns. The specific growth rates of the test prawns was directly related to their new relative size ranking (Ra'anan 1982; Ra'anan & Cohen 1985). Whether jumpers and laggards would respond similarly was not investigated. Studies on growth of juveniles indicate the complexity of the effects of size ranking of prawns in their original population on their subsequent growth. On the one hand persistence in growth rate in isolation or in their original environment has been found. However, on the other hand plasticity and adjustability by shifting to higher or lower growth rates according to changes in relative size rank in a new social environment have also been reported.

Growth variation in juvenile prawns has been initially studied independently from the growth patterns of mature populations (Ra'anan & Cohen 1985). The persistence of differences between jumpers and laggards, particularly in males, up to the time of morphotype differentiation was demonstrated for the first time by Karplus *et al.* (1986b, 1987), who size graded juvenile populations into two and three fractions which they reared separately in earthen ponds. Graded juvenile populations developed different population profiles according to the size fraction (upper, middle and lower), and also differed from that of the non-graded source population. The frequencies of the SM morphotype in the graded populations were 50, 32 and 8% in the lower, middle and upper fractions, respectively. BC males showed the reverse trend with 3, 10 and 22% in the lower, middle and upper fractions, respectively. The frequency of OC males also increased significantly from the lower fraction (42%) to the upper fraction (63%). Thus, male jumpers were found to develop mainly into BC and OC males, while laggards developed mainly into SMs (Karplus *et al.* 1986b, 1987). Comparison of a size-graded population with a non-graded population with similar mean weights at stocking revealed significant differences in male morphotype frequencies at maturity. These results indicated the overriding importance of the relative position in the original population compared with absolute weight (Karplus *et al.* 1986b). The effects of size grading on female reproductive states are less pronounced and seem to operate mainly through the change in mean size at stocking.

Finding the earliest point at which a specific growth pattern, which will be maintained through maturation, is established is important for management of size variation. Initial studies on size grading were carried out on populations that were 5 months old and had reached a mean weight of 1 to 2 g (Karplus *et al.* 1986b, 1987). In subsequent studies, Daniels & D'Abramo (1994) and Daniels *et al.* (1995) demonstrated that much younger populations, at 50 to 60 days after metamorphosis, with a mean weight of 0.11 to 0.16 g, already display an early determination of future growth as evidenced in the culture of size-graded populations.

Malecha (1977) noted no difference in final mean weight of sibling prawns segregated by time of metamorphosis and reared in the laboratory for a period of 13 months. Sandifer & Smith (1979) found that early-metamorphosing PL raised separately retained a size advantage over the late-metamorphosing ones for 3 months, because of the longer period of post-larval development which compensated for their initial smaller size at metamorphosis. Following this period the separately raised late-metamorphosing PL attained a similar mean weight to that of the early-metamorphosing PL because of relatively higher growth rate. Late-metamorphosing populations and control populations (i.e. composed of both early- and late-metamorphosing PL), raised separately in earthen ponds, had similar mean weights and male morphotype compositions, thus further confirming that growth pattern determination occurs after metamorphosis (Karplus *et al.* 1990). The effect of time of metamorphosis on the prawn sex ratio is uncertain, because there are conflicting reports in the literature. Howlader & Kiortsis (1978) reported the occurrence of a higher frequency of males in early-metamorphosing prawn larvae, on the basis of a small sample of laboratory-raised juveniles. Karplus *et al.* (1990) reported an equal sex balance in early-metamorphosing larvae in one study, and a higher proportion of females in another study, both studies being based on large populations raised in earthen ponds.

Although growth pattern determination occurs only several weeks after metamorphosis, early hatching and metamorphosis times may confer a competitive advantage, with consequences for future growth. This effect cannot be evaluated by separate culture of different fractions but requires that differently marked larvae and PL be raised together. Zacarias (1986) overcame this difficulty by using genetically marked larval populations. A positive correlation was demonstrated between hatching time and post-larval metamorphosis time and juvenile size of broods whose hatching time differed by 2 or 3 days. Early-hatching larvae are likely to become early-settling PL, which, in turn, are likely to become relatively larger juveniles (Fig. 16.5a–c). The social interactions among juveniles lead to the emergence of jumpers and laggards, and to the fixation of a specific growth pattern that will eventually lead to the development of different morphotypes of sexually mature males. Hatching time is thus the earliest event which affords some

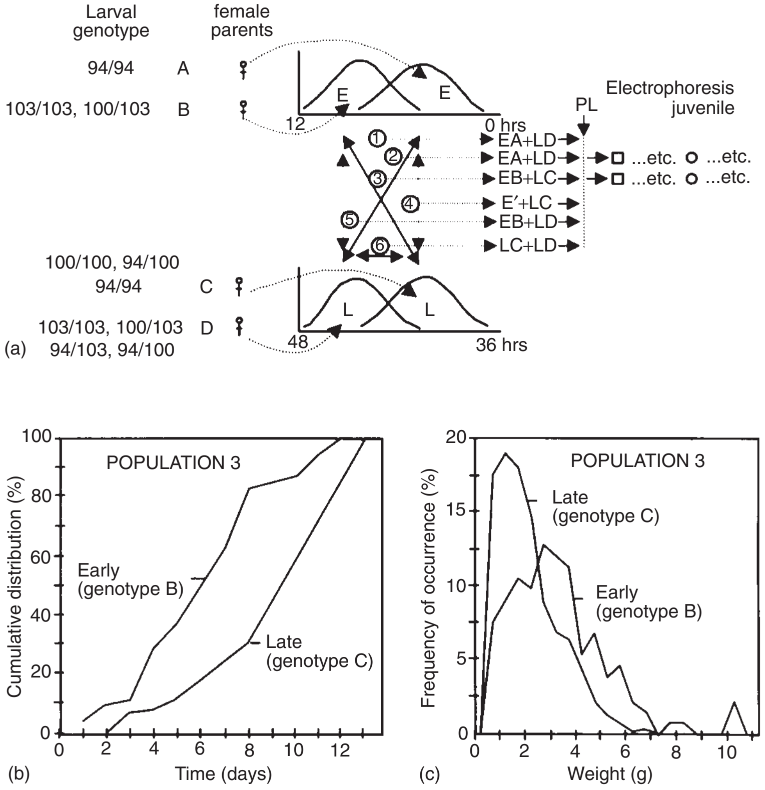

Fig. 16.5 (a) Experimental design for the formation of genetically distinguishable genotypes of early- and late-hatching groups Key: A, B, C and D represent genetically distinguishable genotypes. E and L represent early- and late-hatching groups. Encircled numbers represent the constructed populations. (b) Cumulative distribution (%) of early- and late-hatching larvae metamorphosing to postlarvae (PL) as a function of time (days) since metamorphosis was observed. (c) Weight distribution of early- and late-hatching larvae after 120 days of juvenile grow-out. (Source: after Zacarias, 1986.)

possibility of prediction of the future development of an individual due to the possession of a competitive edge. Further research is needed to establish whether the hatching time differential within a brood (one to two nights – Wickins & Beard 1974) is sufficient to create a competitive edge, and whether the hatching time is related to egg size or egg position on the pleopods. In this regard, Kulesh & Guiguinyak (1993) showed that in *M. nipponense* the largest females, which became sexually mature first, were the earliest to metamorphose and had hatched from the smallest eggs in a clutch. In this species, embryogenesis duration at steady temperatures was directly proportional to egg volume (i.e. the smallest eggs were the first to hatch – Mashiko 1987).

16.3.2 Physiology of sexual and morphotypic differentiation

Sexual differentiation in crustaceans is largely regulated by a gland, which was first described by Cronin (1947) and later termed the androgenic gland (Charniaux-Cotton 1954). In decapods this gland is usually located at the sub-terminal portion of the sperm duct. The cells may be arranged as thin, parallel and anastomosing cords (Carpenter & DeRoos 1970) or in a compact, lobed structure (Kleinholz & Keller 1979). A combination of the two structures was found in *M. rosenbergii*, in which the androgenic gland is composed of strands of cells surrounded by a thin layer of connective tissue, forming a pyramidal cluster loosely associated with the posterior portion of the ejaculatory duct (Veith & Malecha 1983). Awari & Kiran (1999) have recently provided a histological and histochemical description of the gland in *M. rosenbergii*. Charniaux-Cotton (1954) was the first to suggest a regulatory role for the androgenic gland and showed that bilateral androgenic gland ablation (andrectomy) in *Orchestia gammarella* blocked differentiation of secondary male characteristics and resulted in decreased spermatogenesis. Once the external male sexual characteristics are formed in gonochoristic shrimp, the androgenic gland is not needed for their maintenance (Touir 1977). The role of the androgenic gland in the regulation of the development of decapod external sex characters is well established (Charniaux-Cotton & Payen 1988).

Nagamine *et al*. (1980) demonstrated that the presence of the androgenic glands in *M. rosenbergii* is necessary for the development and regeneration of male secondary sexual characteristics. These studies were, however, carried out before the existence of the different morphotypes had been recognised. Nagamine *et al*. (1980) operated on two types of males with appendix masculina, which they termed stage 2 and stage 3. Kuris *et al*. (1987) suggested that these stages represent the SM and OC morphotypes. In the experiment of Nagamine *et al*. (1980), operated SMs developed ‘immature chelipeds’ that were slimmer, shorter and less spinous than ‘mature chelipeds’. Operated OCs did not lose their ‘mature chelipeds’ but, if ablated, were unable to regenerate ‘mature chelipeds’. The morphotypic differentiation process begins with sexually immature males which possess a pair of gonopores, with flap at the base of the fifth pereiopod but which lack an appendix masculina on their second pleopod (Tombes & Foster 1979; Nagamine & Knight 1980; Snir 1992). These juvenile males develop into the SM morphotype when the appendix masculina develops without any allometric change in the claw segments (Kuris *et al*. 1987). Small males may develop rapidly, and irreversibly transform into the large BC morphotype, via the WOC and SOC morphotypes. These transitional rapidly growing SMs, although not differing in their external morphology from the stunted SMs, differ in their growth rate and probably in their lower gonado-somatic index. Alternatively, SMs may remain as such for shorter or longer periods of time, displaying a reduced growth rate and a high gonado-somatic index. These processes depend on the presence and function of the androgenic gland, as demonstrated by the amputation of the second pleopod and monitoring of the regeneration of the appendix masculina (Snir 1992).

The role played by the androgenic gland in the male developmental pathway and growth was further analysed by Sagi *et al*. (1990). The androgenic gland was found to be essential for the continuation of the morphotypic differentiation process. Figure 16.6 summarises the delaying effect of androgenic gland ablation during the morphotypic differentiation process in *M. rosenbergii* (Sagi 1990). The normal differentiation process is described in line 1 of the figure. When andrectomy is performed on SOC males (Fig. 16.6, line 2) dif-

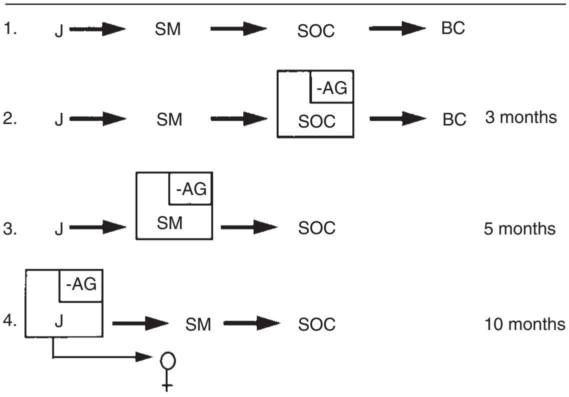

Fig. 16.6 The effect of andrectomy on the male development pathway. (Source: after Sagi, 1990.)

Key: J = juvenile; SM = small male; SOC = strong orange claw; BC = blue claw male; AG = androgenic gland ablation. The number of months between the andrectomy and the end of the experiment are indicated on the right side of the figure.

ferentiation continues and leads to the BC morphotype. Andrectomised SMs (Fig. 16.6, line 3) differentiate into SOC males, but further differentiation into BC males is prevented. When the andrectomy was performed on immature males (Fig. 16.6, line 4) a wide range of abnormalities in gonadal development was observed, the nature of which depended on the age at which the andrectomy had been performed (Sagi *et al.* 1997b). Development of reduced testes was observed in males andrectomised at a relatively old age. In males andrectomised when younger, partly testicular and partly ovarian gonads ('ovotestes') or abnormally lobulated ovaries developed (Snir 1992). In the males andrectomised at the earliest age, complete sex reversal, leading to the development of functional females capable of mating and producing progeny, was achieved (Fig. 16.6, line 4).

Monitoring the regeneration of the appendix masculina shortly after andrectomy enabled Snir (1992) to eliminate 'failures' early and to culture only andrectomised males that were more likely to change into 'neo females'. Another important physiological characteristic of each male morphotype is its growth rate. Different male morphotypes in a monitored developing population had significantly different instantaneous or specific growth rates (Ra'anan *et al.* 1991). The OC males showed the highest growth rates (R = 1.22 ± 0.4% per day) which decreased with the increase in the natural logarithm of body weight. Blue claw males had the lowest growth rate (R = 0.07 ± 0.04% per day) which was relatively constant over size. Small males had an intermediate growth rate (R = 0.82 ± 0.33 per day), relatively constant over size. In this young developing population studied by Ra'anan *et al.* (1991), the SMs readily transformed into OC males and do not represent the stunted individuals of this morphotype found in mature populations. The androgenic gland also has a role in the growth regulation of *M. rosenbergii*, as indicated by the reduction in growth rates of andrectomised SM and OC males compared with untreated or sham-operated controls. In general, andrectomised males exhibited a reduced growth rate, which was similar to the growth rate of normal females (Sagi *et al.* 1997b).

16.4 Factors controlling growth variation

16.4.1 Genetic control

16.4.1.1 Intraspecific variation and hybridisation

Macrobrachium rosenbergii is found over a wide geographical range and can be divided into three distinct 'ecotypes' based on colour patterns and morphological differences (Malecha 1980): (1) a 'Western' ecotype found in India, Sri Lanka, Burma (Myanmar), Thailand, Malaysia and Indonesia; (2) an 'Australian' ecotype found in Northern Australia; and (3) a 'Northeast' ecotype found in southern Taiwan, the Philippines and Palau in the Micronesian Marshall Islands. Morphometric (Lindenfelser 1980, 1984; Malecha 1984) and electrophoretic (Hedgecock *et al.* 1979; Stelmach 1980) analyses dichotomise the species into Eastern (including the Australian and the Northeast ecotypes) and Western groups. The information regarding size variation discussed in this chapter applies to the Western ecotype, the most widely aquacultured form. Most cultured populations found outside the natural range of this species can be traced to broodstock imported to Hawaii from Penang (Malaysia) by Takuji Fujimura for the development of techniques for the mass rearing of larvae in culture (Fujimura & Okamoto 1972). These animals and their descendants have become known as the 'Anuenue stock' (Malecha 1977), after the Anuenue Fisheries Research Center in Hawaii, where Fujimura conducted his research.

The morphological differences among the ecotypes are small except for some colour variation (Malecha 1980). There appears to be no major difference among the ecotypes in size variation, although the Australian ecotype has been observed to be more aggressive and to show a more pronounced skewness in its size distribution (Malecha *et al*. 1980). The prawn ecotypes interbreed freely, with no evidence of intraspecific reproductive barriers (Malecha 1987). Gomez Diaz (1987) found no major differences in larval development among three Western ecotype stocks and their hybrids. However, Sarver *et al*. (1979) demonstrated differences in larval growth between the Australian and Anuenue ('Western') ecotypes. Dobkin & Bailey (1979) found evidence of improved growth in progeny from crosses of parents from Thailand and Malaysia. Interspecific hybrids between *M. rosenbergii* and *M. malcomsonii* have been produced (Sankolli *et al.* 1982) indicating incomplete reproductive barriers between species within the genus (Shokita 1978). No comparisons were carried out between interspecific hybrids and parental stocks with regard to size variation.

16.4.1.2 Heritability

Meewap *et al*. (1994) estimated the genetic control ('heritability, h^2') of size of mixed sex prawn juveniles at 23 weeks and found low h^2 values (<0.09). Malecha *et al*. (1984) estimated the h^2 for size in juvenile males and females from 50 full and half-full sib families nested within 16 sires in an unbalanced design. Postlarvae were reared in separate compartments for up to 311 days, and reached mean weights of 2.4 and 2.3 g for females and males, respectively. Heritability of prawn size was found to be a sexually dimorphic trait, with females exhibiting significant genetic control (h^2 ~0.35) of size variation, while in males the genetic control of size variation was close to zero. A similar phenomenon, namely a sex-linked control of size variation, has been reported for catfish (El-Ibiary & Joyce 1978). On the basis of their study Malecha *et al*. (1984) concluded that heterogeneous individual growth in male prawns is non-genetic and is controlled by intra-population environmental-social factors. On the other hand a genetic improvement in prawn growth could be achieved by a selection programme carried out on females.

16.4.1.3 Inbreeding effects and domestication

The prawn farming industry has attributed declines in total grow-out productivity and individual growth rate to inbreeding and the degeneration of the cultured stocks, caused by small (i.e. Anuenue stock-based) gene pools (Hanson & Goodwin 1977). Similar attribution continues (Chapter 17). Heritable changes occur as the result of natural selection within the culture environment (Doyle & Hunte 1981). Doyle *et al.* (1983) argued that such changes are important in *M. rosenbergii* culture and that collecting broodstock from ponds as early as possible in the production cycle would be a simple but effective improvement in management strategy. Similarly, Ra'anan (1987) suggested that selecting the earliest maturing females as broodstock would improve the genetic base because these are also the fastest-growing females. Malecha *et al.* (1980) and Sarver *et al.* (1979) found little differences between the cultured and wild prawn stocks with similarity in size frequency distribution of communally reared Anuenue and Malaysian wild stocks. Malecha (1983b) argued that the high larval survival in prawn hatcheries, compared to larval survival in nature, has served to broaden the prawn gene pool in a manner similar to that described by Carson (1968) for the genetic events occurring during rapid speciation following colonisation. Moreover, detrimental inbreeding effects can be avoided in highly fecund species (Kimura & Crow 1963), such as prawns, and are not, *ipso facto*, inevitable in the descendants of numerically small founder stocks, such as the Anuenue stock.

16.4.2 Environmental control

Most studies on environmental effects (e.g. of temperature, salinity and food) on communal culture of *M. rosenbergii* have examined the growth rate and survival of juveniles, without paying attention to size variation. Few studies actually attempted to examine specific environmental effects on the structure of sexually mature populations.

The effects of three temperatures (20, 24 and 29°C) on the size distribution of juvenile prawns of two genetic strains (Anuenue and Malaysian) revealed significant differences among temperatures and no difference between genetic stocks, in the skewness of the size distributions (Malecha *et al.* 1980). The effect of temperature on prawn population structure was also evaluated by comparing sexually mature prawn populations raised at two different latitudes (Tidwell *et al.* 1996). Prawns raised in relatively cool seasonal water temperatures averaging 24 to 26°C (Kentucky) were compared with those raised in a warmer climate, with a seasonal average of approximately 30°C (Mississippi). At both localities ponds were stocked on the same day with similar-sized juveniles, produced in the same culture tank and fed the same quantity and type of food. At harvest, the male population structures at the two latitudes were similar, despite differences in water temperatures. In contrast to the case of males, lower temperatures resulted in a shift in female reproductive state (i.e. fewer berried females and more virgins), because of a temperature-mediated delay in onset of reproductive maturity. Temperatures, however, were high enough to support rapid growth, which resulted in unexpectedly superior production at the higher latitudes.

The effects of three salinities (0, 5 and 10 p.p.t.) on the size distributions of juvenile prawns of two genetic stocks (Anuenue and Malaysian) revealed significant differences among salinities and no difference between stocks in the skewness of the size distributions (Malecha *et al.* 1980).

Two studies specifically aimed at comparing the effects of different feeds on mature prawn population structure have been carried out, and yielded similar results. Differences in diet protein sources (0, 7.5 and 15% fish meal) had no effect on male morphotype composition and a minor effect on females (Tidwell *et al.* 1994). The nutritional regime (i.e. complete and supplemental diets, with and without organic pond fertilisation) did not significantly influence the proportions of the different male morphotypes or of the female reproductive states, whether measured by number or by weight (Tidwell *et al.* 1995).

Betaine, added as a feeding attractant 2 h after the provision of feed, resulted in a burst of food-seeking behaviour in juvenile prawns, which led to a 17% increase in mean weight. A significant increase in the size distribution occurred concomitantly with the general increase in growth rate, because of the reduced growth of some of the smaller individuals (Harpaz 1997). Although this study concerned food and enhanced feeding behaviour, the effects on size variation were probably mediated through competitive interactions among the prawns (see section 16.4.3).

16.4.3 Social control of growth

The involvement of social interactions in the regulation of growth in *M. rosenbergii* was suggested for the first time in the pioneering studies of Fujimura & Okamoto (1972) on selective harvesting. The removal of large individuals from prawn populations raised in ponds resulted in compensatory growth of the smaller remaining prawns. Subsequent laboratory studies revealed that juveniles raised in social isolation grew more uniformly than those raised in groups, and they did not develop jumpers and laggards (Ra'anan & Cohen 1984b). Stunted SMs grew rapidly and developed into large BC males after isolation (Ra'anan & Cohen 1985).

Four social mechanisms have been hypothesised to suppress growth in crustaceans:

(a) *Direct competition for food*: aggressive and dominant individuals may deprive subordinates (smaller individuals) of food (Segal & Roe 1975).
(b) *Appetite suppression in subordinate individuals*: agonistic interactions result in the establishment of a size hierarchy in which subordinates may grow less rapidly even in the constant presence of food, because of their lower food intake (Cobb *et al.* 1982).
(c) *Decreased food conversion efficiency*: smaller subordinate individuals may have a lower food conversion efficiency (Karplus *et al.* 1992b).
(d) *Increased motor activity*: small subordinate individuals may be engaged in continuous evasive manoeuvres to escape from dominant ones, which results in high energy expenditure and reduced growth (Cobb *et al.* 1982).

The review presented in this section of the chapter addresses the social mechanisms regulating growth in the three sexually mature male morphotypes. Numerous studies of juvenile prawns have addressed the social mechanisms which regulate growth (Segal & Roe 1975; Malecha 1977; Malecha *et al.* 1981a; Pierce & Laws 1982; Karplus *et al.* 1989; Li 1989; Diaz *et al.* 1990), and the sensory modalities involved in these mechanisms (Howe 1981; Malecha *et al.* 1981a; Ra'anan 1982; Ra'anan & Cohen 1984b; Moore *et al.* 1985; Cross 1987; Juarez *et al.* 1987; Corredor-Cantrelle 1989). Although these studies are beyond the scope of this review, the social mechanisms controlling growth in juveniles will be briefly discussed because of their importance for the understanding of size variation development.

Disproportionate food acquisition through direct competition (a) has been found to occur in groups of juvenile prawns when food was limited, and to influence weight gain (Segal & Roe 1975; Li 1989). Aggression in group-raised juveniles, with food provided *ad libitum*, was positively correlated with growth but not with food consumption. Appetite suppression (b) probably does not operate in juveniles of this species. Aggressive individuals grew faster than submissive ones, not because of their greater food intake but, possibly, because of a lower feed conversion ratio (FCR) (c) (Li 1989). Pierce & Laws (1982) reported a marked increase in lipid and carbohydrate synthesis at the expense of protein synthesis in juveniles, when they were exposed to sudden stress caused by crowding. A similar metabolic shift could underlie a high FCR in submissive juveniles or in small males (see section 16.4.3.2).

16.4.3.1 Growth enhancement of OC males – the 'leapfrog' growth pattern

The transition from the OC to the BC morphotype was termed metamorphosis because a dramatic change occurred in the lengths of the claws, particularly in the propodus and carpus, and in claw coloration and spination (Kuris *et al.* 1987). Ra'anan & Cohen (1985) suggested that the transition from the rapidly growing OC to the slowly growing BC morphotype followed a 'leapfrog' growth pattern. An OC male was suggested to metamorphose into a BC male only after it had become larger than the largest BC male in its vicinity (Fig. 16.7a). This hypothesis was based on the observation that the amount of algae covering the claws and carapace of BC males was inversely related to the size of the animal. Body coverage by epibionts was suggested by Smith *et al.* (1979) to be a reliable indicator of the time elapsed since the last moult. The smallest BC male was the most heavily covered with algae and, therefore, had been the first to metamorphose. The presence of this BC male then delayed the transition of the next OC male to the BC morphotype, causing it to attain a larger size following its metamorphosis. Additional indirect support of the 'leapfrog' growth pattern came from a pond and laboratory study of the testicular and sperm duct index in BC males (Daniels 1993): small BC males collected from a mature pond population had small mean testicular indices and large mean sperm duct indices similar to those of the oldest BC males (i.e. the most days post-metamorphosis) from a monitored BC population raised in aquaria.

A more direct testing of the 'leapfrog' growth pattern was carried out by bi-weekly monitoring of the growth and morphotype differentiation in individually marked male prawns that had been stocked as juveniles into cages placed into fishponds (Karplus *et al.* 1991). These males were predetermined to develop into the OC and BC morphotypes, since they originated from the upper fraction of a nursed population (Karplus *et al.* 1986b, 1987). Male and female prawns were stocked at a density of $4/m^2$ and a sex ratio of 1:1, either into very large cages for communal culture or into small cages for paired culture. In eight out of nine transformations in communal culture, the newly transformed BC male was more than 45% larger than the largest BC male previously present. Of the single males stocked into small cages, 60% transformed into BC males, while only 22% did so in communal culture. This difference is probably due to interactions with large BC males, which would delay metamorphosis in group-raised OC males. The results of this study generally fitted the Ra'anan & Cohen (1985) theoretical model. The main difference was that the actual situation was more complex, often with several prawns metamorphosing within a relatively short time span. Their sizes, covering a wide range, were larger than those of the BC males already present (Figs 16.7b and c).

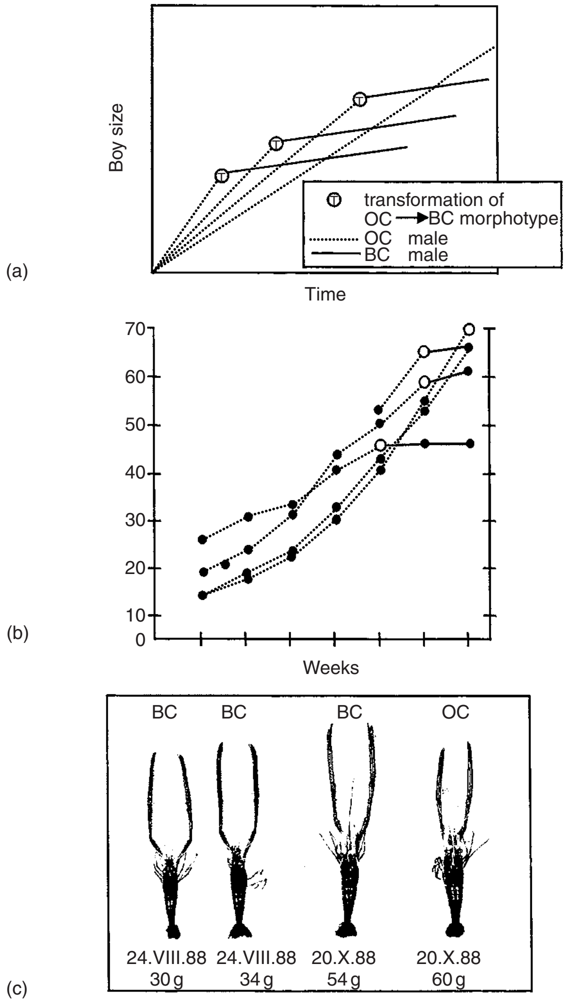

Fig. 16.7 (a) Theoretical 'leapfrog' growth pattern of orange claw (OC) and blue claw (BC) males. (Source: after Ra'anan & Cohen, 1985.) (b) Actual 'leapfrog' growth pattern in a large communal cage. Key as in Fig. 16.7(a). (Source: after Karplus *et al.*, 1991.) (c) An example of male prawns involved in the 'leapfrog' growth pattern present in a large communal cage at harvest time. Note: observe the different claw to body ratios in blue claw (BC) and orange claw (OC) males. (Source: after Karplus *et al.*, 1991.)

Laboratory studies on the 'leapfrog' growth pattern, which focus on the sensory modalities involved and the controlling behavioural mechanisms, are extremely difficult to carry out because of intense cannibalism (Karplus *et al.* 1991; Daniels 1993). Daniels (1993) banded the prawns' claws and glued their dactylus to the propodus in order to reduce cannibalism. However, he was not able to replicate the 'leapfrog' growth pattern in the laboratory, as there was no significant difference between the sizes at metamorphosis of OC males raised with either large or small BC males. Possibly, as suggested by him, the manipulation of the claws may have affected the BC–OC interactions which regulate the 'leapfrog' growth pattern (see also section 16.4.3.2).

16.4.3.2 Growth suppression of runts – blue claw and small males

The role of the bull's claws in the suppression of the growth of runts has been analysed, since all four mechanisms hypothesised to suppress growth in crustaceans [see (a)–(d) in the introduction to section 16.4.3] include an element of aggression, which is manifested among clawed crustaceans by means of these appendages (Karplus *et al.* 1992a). Runts were raised for 112 days in aquaria, paired with an intact bull, a bull with dactyli immobilised by rubber bands or a bull with ablated claws. A group of isolated runts served as a control. Growth of SMs, their motor and maintenance activities, and their social interactions with the bull were monitored. Claw ablation and dactylus immobilisation in bulls resulted in a complete removal of growth suppression in runts, which grew similarly to the controls (Fig. 16.8). The growth of runts raised with bulls with intact claws was stunted because of the reduced growth increment per moult, while the rate of moulting remained the same as in the fast-growing isolated individuals. Runts were occasionally found to become smaller following a moult. This phenomenon has been described only in crustaceans with a large number of missing appendages, and is ascribed to a high regeneration load (Hopkins 1982; Skinner 1985). The claws of the American lobster *Homarus americanus* have also been found to play a major role in growth suppression. However in this species, as distinct from *M. rosenbergii*, the removal of claws shortened the time interval between two successive moults in the subordinate individuals (Cobb & Tamm 1974; Cobb *et al.* 1982).

The motor activity of runts with suppressed growth was the lowest among all experimental

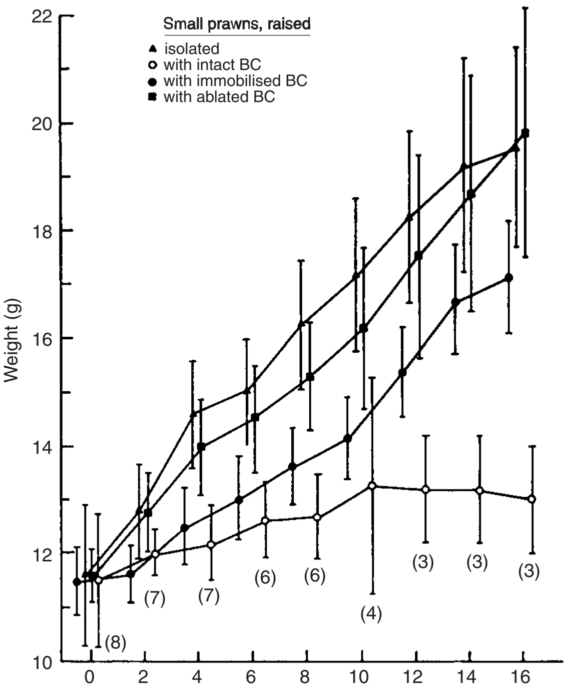

Fig. 16.8 Growth curves (means ± standard error) of small males raised in isolation, with an intact blue claw (BC) male, with a BC male with an immobilised dactylus and with a claw-ablated BC male. Note: numbers accompanying the lowest curves represent the number of surviving small males. (Source: after Karplus *et al.*, 1992a.)

groups. Increased energy expenditure caused by the motor activity of runts was ruled out as a growth-controlling mechanism (d), under the experimental conditions of that study. The possible involvement of the three remaining mechanisms that had been hypothesised to control growth suppression in crustaceans [i.e. direct food deprivation (a), appetite suppression (b), and low food conversion efficiency (c)], were tested in runts (Karplus *et al.* 1992b). Runts were raised for 28 days, either paired continuously with an intact BC male, paired with an intact BC male except for the daily 2-hour feeding session, or grown in isolation. Food competition did not seem to be a major mechanism in controlling growth of runts, since runts separated from the bull during feeding grew at the same rate as those feeding together with the bull. The amounts of food ingested by rapidly growing isolated runts and by stunted runts, isolated only during feeding, were similar, thus ruling out appetite suppression as a major mechanism controlling growth. Food conversion efficiency seems to be the major mechanism controlling growth suppression in runts since isolated runts had an FCR half of that of runts isolated only during feeding sessions. The high FCR of runts in the proximity of a bull was found to be reversible: it shifted to a low (= more favourable) ratio upon the removal of the bull (Karplus *et al.* 1992b).

The role played by various sensory cues (tactile, visual and chemical) originating from BC males in growth suppression in runts was analysed in a series of controlled experiments (Malecha *et al.* 1981a). Runts were placed on one side of an aquarium which was divided in two by a partition of one of several types (opaque or transparent, perforated or intact, or made of a coarse mesh screen), which transmitted a single sensory cue or various combinations of cues, and a large BC male was placed on the other side of the partition. All the experimental treatments tested in this study, except for the full contact, barrier-free control, failed to induce growth suppression in runts.

16.5 The biological significance of size variation

16.5.1 The 'leapfrog' growth pattern – orange claw and blue claw males

The social organisation of prawn populations can provide some insight into the function of the 'leapfrog' growth pattern. The effects of size and morphotype on dominance rank in groups comprising OC and BC males, each represented by prawns in three size categories, were studied in the laboratory (Barki *et al.* 1992). Blue claw males dominated OC males, irrespective of size, probably because of their larger claws. The fact that the alpha position (the most dominant male) was occupied by the largest BC male was already evident from the first day, while a linear rank order became evident only on the second and third days. The consequences of dominance were reflected in competition for resources. The alpha male had clear priority of access to food and shelter. The prawn that had metamorphosed to the BC morphotype and was larger than any other BC in its vicinity, following the 'leapfrog' growth pattern, obtained for at least some time the alpha position in the male dominance hierarchy. Symmetrical and asymmetrical contests (i.e. encounters between prawns matching in size and differing in size, respectively) between BC males revealed that a difference of over 30% in weight ensured the victory of the larger prawn (A. Barki, unpublished data). A mean difference of about 45% in weight between successively metamorphosing prawns was found. This large difference apparently ensures victory in a contest with any other BC male already present at the scene (Karplus *et al*. 1991).

The 'leapfrog' growth pattern results in the gradual descent in the social rank of BC males. When a new and larger BC male appears on the scene the ranks of all BC males present before that event fall. Schmalbach *et al*. (1984) suggested that a voluntary claw autotomy in BC males may take place when the ratio of 1 : 2.8 of body length to claw length (i.e. the sum of the lengths of both chelipeds) is reached, resulting in a subsequent enhanced cheliped growth. The level of 20-hydroxyecdysone in the haemolymph of prawns about to perform voluntary claw autotomy was three times higher than in regularly moulting prawns (Harpaz *et al*. 1987). Voluntary claw autotomy could counteract the lowering of social status of BC males caused by the 'leapfrog' growth pattern. A moulting BC male that voluntarily autotomises its claws temporarily loses its social status completely. However, following a series of moults, it may improve its social status, as a result of its increase in body and, particularly, its claw size, and may also regenerate its spermatogenic tissue, to increase its reproductive potential. The autotomy study was carried out only under laboratory conditions and on isolated individuals. Long-term studies are needed on the dynamic changes in male prawn dominance hierarchies and, particularly, on the changes in social status which follow claw autotomy and the subsequent rapid increase in claw length.

16.5.2 Growth suppression in runts – small and blue claw males

The suppression of growth in runts in the presence of BC males and the contrasting growth acceleration in their absence are adaptive. In natural populations, runts probably represent a reservoir of males able to accelerate their growth upon disappearance of bulls. A similar situation of small non-territorial males, which act as a reserve to replace large territorial males, by rapid growth, was described for a cichlid fish, *Haplochromis burtoni* (Fraley & Fernald 1982). The growth of the small anemone fish, *Amphiprion bicinctus* and *Amphiprion clarkii*, is inhibited when they share the same anemone with a large paired male and female. Rapid growth in these individuals is triggered by the removal of either the large male or female. These small fish, similarly to the prawn runts, serve as a male reserve (Allen 1972; Fricke 1974; Ochi 1986). Runts are better off remaining small as long as bulls are present in high numbers. They attract less aggression from the dominant bull (Barki *et al.* 1991a) and are probably less vulnerable to cannibalism since they can shelter in small crevices (Karplus & Harpaz 1990). Being small and highly mobile, runts can find food on the bottom before being chased away by larger prawns, males or females (Harpaz 1980). Runts may still fertilise females, by means of the sneak mating strategy (see section 16.1.3.2). As bulls become scarce, some runts increase their growth rate, and transform into OC males and, finally, into bulls in accordance with the 'leapfrog' growth pattern.

Actual evaluation of the adaptiveness of heterogeneous individual growth (HIG) for the individual requires long-term field studies (or at least studies under semi-natural conditions) which would quantify the lifetime reproductive success of prawns. Emphasis should be given to a comparison of the lifetime reproductive success of jumpers which transform rapidly into BC males with laggards which spend large periods of time as SMs. Research on the occurrence of growth suppression and male morphotypes in natural populations is important for the understanding of the function of HIG.

16.6 Commercial significance and management of size variation

16.6.1 Supplementary shelters

Early researchers suggested that natural materials such as branches, aquatic plants, gravel and shells should be introduced into juvenile rearing tanks to reduce the number of aggressive interactions and to provide refuges for moulting prawns (Ling 1969a; Fujimura & Okamoto 1972). A variety of shelter types were developed, since natural materials seemed impracticable for intensive rearing systems because of their rapid decay and handling difficulties. Smith & Sandifer (1979b) evaluated the suitability of several habitat configurations (tube pyramids, concave plastic plates placed separately or in stacks, and horizontally and vertically layered habitats), on the basis of their occupation by juvenile prawns. Prawns exhibited a pronounced preference for the layered habitats, particularly for their edges. A strip-layer habitat was designed to maximise this 'edge effect'. In the study of Smith & Sandifer (1979b) the prawn behaviour was elegantly used to guide the development of an efficient habitat. Although horizontal and vertical strip-layer habitats were equally preferred by prawns, the former were preferred by the researchers, as they seemed to be more convenient for prawn feeding. Over the years a variety of shelter types have been developed for juvenile nurseries and for grow-out, in ponds and intensive culture units. The major attributes of a successful commercial shelter, in addition to being attractive to prawns, are low cost, large surface area, ease of installation and removal, and economic storage (Sandifer & Smith 1985).

Several behavioural observations related to shelter occupation indicate their extreme importance for both juveniles and adults. Peebles (1979b) described intense fighting over shelters (see section 16.1.3). Utilisation of shelters by juvenile prawns increased with population density (Peebles 1974). Small males occupied a flower pot shelter most of the time during both day and night in the presence of a BC male, but they only rarely used the shelter when they were isolated or when they shared their aquarium with a large BC male with ablated claws (Karplus *et al.* 1992a).

Although shelters are consistently used in intensive high-density nursery systems and in some grow-out ponds, evidence for beneficial effects is limited. In two experiments, Smith & Sandifer (1975) compared the effects of shelters and of their spatial orientations (horizontal *versus* vertical layer orientation) on prawn survival, growth and FCR. Mortalities were two to four times higher in tanks without shelters than in those with shelters. Feed conversion ratio and prawn biomass were superior in the shelter treatment to those in the no-shelter control. However, the results of this study were based on a very small number of replicates and no statistical analysis was applied to the data. In another study, the addition of substrates to a low-cost, low-density, outdoor nursery system had no significant effect on prawn survival and mean weight at harvest (Mulla & Rouse 1985). However, Mulla & Rouse (1985) found a significant effect on size distribution, which was more normal and uniform in the treatment with shelters. Possibly the minor effect of substrate addition in that study may have been due to the relatively small increase in surface area (8%) and the type of the shelter used.

Studies on the effects of supplementary shelters on grow-out of prawns in ponds have been conducted mainly in temperate climates. Cohen *et al.* (1983) reported that the addition of substrates to ponds stocked with prawns (10 prawns/m^2) increased prawn production by 14% and mean weight at harvest by 13%, with no effect on survival compared with the no-shelter control. In contrast, 1 year later, Ra'anan *et al.* (1984), working at the same research station (Ginosar, Israel), attributed a 24% increase in production to shelters, and found that it was based mainly on an increase in prawn survival at a higher prawn stocking density (15 prawns/m^2) and a different management regime. Both these studies, which lacked statistical analysis of the data, emphasised that supplementary shelters increased the efficiency of selective harvests, thus extending the period of fresh prawn production. Tidwell *et al.* (1998) evaluated for the first time the effects of added substrates (horizontal plastic mesh and vertically suspended seines) on prawn population structure. At harvest, the mean weight and total yield were higher by 20% in ponds with added substrates, this increase being very similar in magnitude to that in surface area increase. In ponds without substrates the number of SMs was significantly higher and the number of OC males significantly lower than in ponds with added substrates. Average mean weights of BC males, OC males, and berried, spent and virgin females were significantly higher in ponds with added substrates. However, in a more recent study Tidwell *et al.* (1999) were unable to repeat these results and found no significant effect for added substrate on prawn population structure, possibly because different stocking rates were used.

The addition of artificial habitats to prawn culture units probably operates in two beneficial ways. Firstly, they increase survival by providing the freshly moulted individuals with a shelter when they are particularly vulnerable to cannibalism (Peebles 1978). Secondly, they increase the surface area available to prawns, and concomitantly decrease the frequency of the agonistic interactions that have been demonstrated to suppress growth (Karplus *et al*. 1992a,b; see also section 16.4.3). Artificial shelters thus probably operate in a way similar to density reduction, as suggested by Tidwell *et al*. (1998); in both cases the proportion of SMs decreases, that of the large male morphotypes increases, and morphotype mean weights increase (Karplus *et al*. 1986a).

16.6.2 Selective harvesting

Fujimura & Okamoto (1972) were the first to recommend the selective removal of the larger, faster-growing animals with a large mesh net in order to manage the variable growth pattern of the prawns. As the remaining prawns grow into larger size classes they too are periodically seined out. The selective harvest of large animals was considered to reduce competition for resources (food, oxygen and shelter) and promote increased growth rates among the remaining prawns. Selective harvests are particularly relevant in warm climates, where adequate year-round water supply is available, and are less practised during the short grow-out period in temperate climates. They are conducted at 2- to 3-week intervals in year-round growing seasons, and capture the BC males, the largest females and the largest OC males. This system has been described as the 'traditional' (Malecha 1983a) or 'continuous' (Lacroix *et al*. 1984) system. In single 'batch' harvests these animals provide the largest proportion of the harvest revenue (Smith *et al*. 1980) but the large numbers of SMs can limit economic production (D'Abramo *et al*. 1991; Daniels *et al*. 1995). The SMs and other undersized morphotypes, which are not harvested in efficient selective harvests, can undergo 'compensatory' growth (an accelerated change in their growth rate), allowing them to occupy the 'size niche' vacated by the harvested, larger, dominant animals. Unfortunately, selective seine net harvests are very inefficient in capturing all the harvestable product because of the cumbersome movement of the large seine nets through large pond volumes and along uneven pond banks and bottoms (Lam & Wang 1986). Harvest efficiency has been estimated either by actually draining ponds after the harvest and counting the number of marketable prawns that should have been removed, or by using a mark-recapture method (Wang & Lam 1986). Harvest efficiencies ranging between 50 and 75% have been reported (Williamson & Wang 1982; Malecha 1983a). Several improvements have been introduced into the labour-intensive manual harvesting operations (Williamson & Wang 1982; Wang & Lam 1986). These improvements included the use of a low-cost, lightweight boom to replace the harvest crew in the pond, and a tractor to pull the seine nets. Although these improvements helped to save labour and reduce harvesting time, they did not solve the harvesting efficiency problem. Inefficient pond harvests result in lost revenue in two ways: by not harvesting all the harvest-sized animals and by under-managing the behaviour-based compensatory growth capability of the undersized sub-dominant morphotypes. Commercial prawn populations can be optimally managed only by a complete harvest, which, realistically, can be accomplished only through pond draining and removal of all the large dominant animals.

16.6.3 Size grading

Malecha *et al*. (1981b) suggested a multi-stage, rotational stocking and harvesting system for year-round prawn monoculture, to replace the traditional continuous stocking and harvesting system. The major drawbacks of the traditional culture system are: inefficient management of the HIG of prawns, inefficient and labour-intensive harvesting, high mortalities among PL stocked into ponds containing large prawns, and inefficient management of 'residence time', and 'optimal standing crop'. The rotational stocking and harvesting system is based on stock manipulation, pre-harvest size grading, and efficient harvesting through pond drain-down whereby market-sized animals are removed and undersized individuals are restocked (Fig. 16.9). This culture system emphasises the dynamic use of ponds by stocking them at

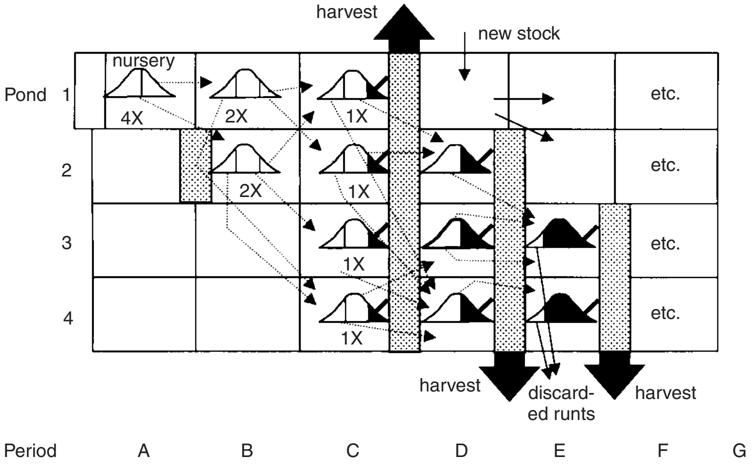

Fig. 16.9 A four-pond multi-stage rotational scheme with size grading. Note: dotted arrows represent stock division and rotation to homogeneous size classes. Shaded areas in distributions represent harvested class. Hatched bars between periods represent harvest. Periods can be of different lengths. X represents a certain density which may vary at each stage depending upon empirically derived growth rates. (Source: after Malecha *et al.*, 1981b.)

differing densities with size-graded fractions of the population (upper, medium and lower fractions). The rationale underlying the management of HIG by size grading and re-stocking prawns was based on compensatory growth of small individuals after the removal of large ones, as reported in salmonids (Gunnes 1976), carp (Nakamura & Kasahara 1957) and prawns (Willis & Berrigan 1978).

Preliminary reports from Hawaii on prawn size grading in monoculture, combined with stock rotation, indicated increases in prawn mean size and yield and a decrease in the time from stocking to harvest, in size-graded populations compared with non-graded control groups (Malecha & Bigger 1984; D'Abramo *et al.* 1991). The idea of managing HIG by pre-harvest size grading, which was developed in Hawaii (Malecha *et al.* 1981b), was adapted to the short grow-out season of temperate zones (e.g. Israel, Mississippi, and Kentucky) by size grading nursed populations prior to stocking. The stocking of graded large juveniles in intensive monoculture appeared to improve the average weight, yield and FCR compared with stocking non-graded juveniles into similar culture conditions (Ra'anan & Cohen 1983).

Progress in understanding the effects of size grading of prawn populations has been achieved through the careful inspection of its effects on male morphotypes and female reproductive states (Karplus *et al.* 1986b, 1987; D'Abramo *et al.* 1991; Daniels & D'Abramo 1994; Daniels *et al.* 1995). Karplus *et al.* (1986b, 1987) demonstrated for the first time that size grading prawn populations had a profound and persistent effect on male morphotypes, because of the very early determination of the male developmental pathway (see section 16.3.1). Prawns are, in this respect, very different from fish, since grading operations in fish have only a temporary effect and have to be carried out repeatedly to control size variation (Seymour 1984; Wickins 1985; Goldan *et al.* 1998).

The authors of this chapter suggest that determination of the early male developmental pathway is different for the small (SM) and large morphotypes (OC and BC). Large morphotype determination is irreversible. Juvenile prawns from the graded upper fraction of the population develop into the large OC and BC males at a much higher frequency than non-graded populations stocked at the same density (Karplus *et al.* 1986b, 1987; D'Abramo *et al.* 1991; Daniels & D'Abramo 1994). The proportions of the various male morphotypes among upper-fraction prawns were not affected by stocking density (Daniels *et al.* 1995; Siddiqui *et al.* 1997), in contrast to those from non-graded populations (Karplus *et al.* 1986a). Small morphotype determination is reversible, allowing a compensatory shift from the SM to the OC and BC morphotypes in the absence of large prawns. This compensatory shift is time demanding. The proportion of SMs in the lower third of a graded population (50%) was higher than that in the non-graded control population (33%), following 97 days of grow-out (Karplus *et al.* 1987). However, the SM proportion, following a longer, 130-day grow-out (Daniels & D'Abramo 1994), was reduced to 26% in the graded lower third of the population compared with a 34% SM frequency in the non-graded population.

Size grading of nursed juvenile populations (see also Chapter 8) prior to stocking has a profound effect on income, because of the early determination of male morphotypes. The income from upper-fraction prawns has been found to be nine times as great as that obtained from lower-fraction prawns after a short grow-out season of 97 days (Karplus *et al.* 1987). An increase in the weighted income from all graded fractions, compared with that from the non-graded control, can only be achieved during a long grow-out season, which ensures sufficient time for a compensatory shift in male morphotypes. Differences in harvest mean weight of graded populations are mainly associated with changes in the relative proportions of male morphotypes in the harvested population (D'Abramo *et al.* 1991). Following a short grow-out season of only 97 days, grading prawn populations into three fractions did not result in a weighted increase in net income compared with that from the control (Karplus *et al.* 1987). Extending the grow-out season to 135 days resulted in a 22 to 26% increase in weighted profit because of grading (Daniels & D'Abramo 1994). An additional extension of the grow-out season to 165 days resulted in a dramatic change in male morphotype proportions and at least a two-fold increase in income because of grading (D'Abramo *et al.* 1991; Fig. 16.10). Although the above studies were carried out at different localities within the temperate zone, and with some differences in stocking densities, the enhancement of the effect of grading on profit with extension of the grow-out season is clear, which means that the tropical zone is the most suitable for prawn culture, also from the point of view of managing HIG through size grading.

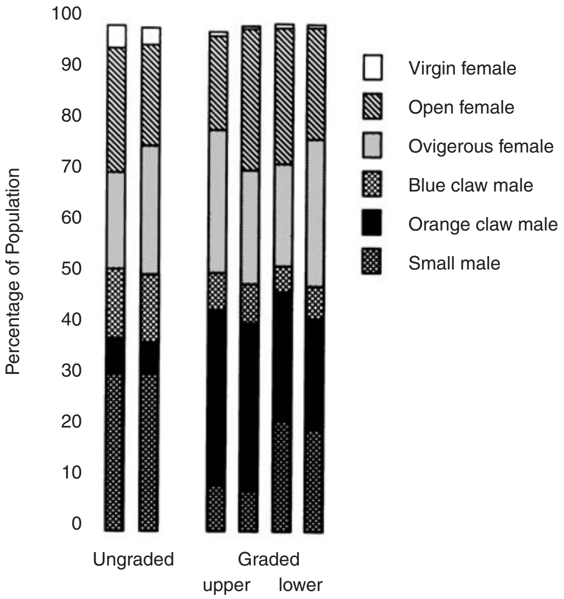

Fig. 16.10 Relative percentages of male morphotypes and female reproductive states at harvest in ponds stocked with upper-graded, lower-graded and ungraded juvenile prawns. Note: the percentage of small males (SM) in the lower-graded fraction is lower than the ungraded control because of a compensatory morphotype shift. (Source: after D'Abramo *et al.*, 1991.)

16.6.4 Monosex and sex reversal

Culture of monosex populations is a common procedure in animal husbandry. Differences between males and females of the same cultured species, in growth rate, alimentary needs and behavioural patterns, dictate the need to establish management systems specifically adjusted to one sex or the other. Moreover, since a monosex culture population is inherently non-breeding, energy is diverted to growth; reproduction can be carried out in separate, controlled systems. The monosex culture strategy has become a common practice in fish culture (Mires 1977; Tayman & Shelton 1978) and more recently attempts have been made to apply it in crustacean culture (Curtis & Jones 1995; Sagi *et al.* 1997a). The first attempt at monosex culture of *M. rosenbergii* was carried out in a small-scale, intensive cage culture system (Sagi *et al.* 1986). An all-male population yielded 473 g/m^2 within 150 days, whereas an all-female population and a mixed population produced 248 g/m^2 and 260 g/m^2, respectively, during the same grow-out period. Not only was the total yield higher under all-male stocking but also prawns of the all-male group reached market size at a faster rate, prolonging the fresh product marketing period and permitting the use of the vacant pond for further production (Sagi *et al.* 1986). Following this small-scale cage experiment, monosex culture was tested under intensive prawn monoculture conditions in earthen ponds, and similar results were achieved (Cohen *et al*. 1988). The all-male stocking also proved superior in total marketable yields, average weight, calculated income per unit area, and time to harvest. The procedure was also tested in polyculture ponds (Hulata *et al*. 1988). However, although all-male stocking yielded an increase of 18% in net income, the conclusions of this study were that the improvement in income was not large enough to justify the implementation of manual sexing, and that an efficient way of producing prawn monosex populations is required.

All-male culture is not necessarily superior to all-female culture, particularly under high-density conditions. The effect of prawn culture density on prawn mean weight (see section 16.2) is more pronounced in males than in females (Karplus *et al*. 1986a). Commercial prawn culture might be improved by using only females, raised under high-density conditions.

Several attempts have been made to study sex heritability in *M. rosenbergii*, by crossing either androgenic gland-ablated males with normal males or androgenic gland-implanted females with normal females. Complete sex reversal in males was achieved by the surgical removal of the androgenic gland in juveniles, leading to the development of functional neo-females capable of mating and producing progeny (Sagi & Cohen 1990). Functional sex reversal of females, leading to the development of neo-males, was achieved by implanting androgenic glands into the youngest and smallest prawns that could be identified as females (Malecha *et al*. 1992). Both studies were incomplete, in the sense that a technology to produce crustacean monosex populations as an aquacultural procedure was not derived from either. However, in both cases, progeny was obtained when fertile sex-reversed animals were crossed with normal prawns. Mating of neo-females with normal males produced almost all males, whereas mating of neo-males with normal females produced a skewed sex ratio in favour of females. The sex ratio of the offspring supported the homogametic male theory, in keeping with Katakura (1989). However, the chromosomal sex-determining mechanism is imperfect because of additional environmental, epigenetic and genetic factors (Malecha *et al*. 1992).

The early trials of monosex culture involved the manual sexing of *M. rosenbergii* populations prior to stocking. This procedure requires skilful workers and is extremely labour-intensive and thus not applicable under farm conditions. All-male populations could be commercially generated by the application of the androgenic hormone, produced in commercial quantities by biotechnological methods such as those used by Sun (1994, 1995, 1997). In the next few years, we shall probably witness such commercial attempts. Further research and development are still needed, to establish a feasible technology for the commercial production of monosex prawn populations.

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17

Commercial Freshwater Prawn Farming Around the World

Michael B. New

The history, and the global and regional status of freshwater prawn farming has been discussed in Chapter 1, which includes the latest official Food and Agriculture Organization (FAO) production statistics and other estimates on the expansion of the sector. The present chapter comprises a compendium of the results of a questionnaire which gathered information about the current status of the commercial aquaculture of *Macrobrachium rosenbergii* at a national level. Information on most of the major producing countries has been obtained through this informal survey. Where appropriate, this information has been supplemented with published information which, to avoid cluttering the text, has been cited in section 17.9. The questionnaire, and the correspondence which ensued, also produced considerable information on the capture fisheries for *M. rosenbergii*, which has been absorbed into Chapter 22. Those who co-operated in providing this information are gratefully recognised in the general acknowledgements section of this book.

A number of fundamental decisions had to be made in assembling the information presented within this chapter. Firstly, there were some divergences of opinion where multiple national questionnaires were returned; the author has therefore used his own judgement and experience in synthesising this material for presentation. Secondly, some readers may have wished to see some form of global summary about the technology employed in commercial freshwater prawn farms and hatcheries at the end of this chapter. However, any examination of the material presented soon shows that farming practices are very diverse. The author therefore decided to avoid the artificial generalisations which such a section would have necessitated, leaving each reader to form his or her own opinion. Other chapters of this book thoroughly review the technical issues, while information on the scale of the industry is reviewed in Chapter 1. Thirdly, some of the information in this chapter could have been presented in tabular form. The author, noting that such tables would necessarily be long and complex, and confusing to read, decided against this option. An exception was made in the case of information on farm-gate and retail prices, which has been grouped within tables. Fourthly, in the belief that many readers may choose to read about activities on a country-by-country basis, the author has structured the chapter by country and region. Finally, it is recognised that some of the numerical statements contained within this chapter may conflict with the analyses presented in Chapter 20 (economics). The author of the current chapter decided that, since much of the information presented here is not supported by documentary evidence, it would be wrong to offer it for analysis within Chapter 20.

In studying the contents of this chapter, the reader will quickly realise that there is little correlation between the scale of national production and the amount of information available. For example, in addition to the description of activities in major producing countries in the eastern and western hemispheres (e.g. China, Thailand, Brazil), considerable detail has been provided about freshwater prawn farming activities in some of the minor producing countries (e.g. in the Caribbean). This information has been presented in full because it is expected to be of interest to the readers of this book. It is worth reflecting on the fact that though the aquaculture production of some small or sparsely populated countries is very low, its relative economic importance within their national economies may exceed that of the major producing nations (New 1997). This applies as much to freshwater prawn farming as it does to other forms of aquaculture.

17.1 Asia

Separate sections on each of the seven major producing countries of Asia have been provided (sections 17.1.1–17.1.7), while the others are grouped together in section 17.1.8.

17.1.1 Bangladesh

Official statistics (FAO 2000) indicate that the production of farmed *M. rosenbergii* in Bangladesh had reached a substantial 48 000 t by 1998, placing the scale of its freshwater prawn farming industry second only to that of China. Annual national production is expected to rise very substantially. Rapid commercial development is reported from the Bagerhat region of Southwest Bangladesh. Khulna is also a major freshwater prawn farming area. There is considerable national surplus processing capacity, and the social and environmental conflicts associated with marine shrimp farming are making freshwater prawn farming more attractive. The major limiting factors at present are seed supply and the need to further extend technical advice. Estimates of the number of freshwater prawn farms vary from 27 000 to 80 000; 70 to 75% are very small (<0.4 ha). Only about 20% rear prawns in brackishwater. The development of some large farms seems to be imminent. One company, Delta Foods and Fisheries Ltd, was reported to have embarked on a programme to establish a hatchery and a 100 ha grow-out farm.

More than 90% of the juveniles used to stock ponds are caught from the capture fisheries of rivers (such as the Meghna, Gori, Pasai, etc.) within 50 to 100 miles of the coast and in beels (natural depressions), using simple push nets to obtain 12 to 15 mm postlarvae (PL). It is estimated that some 200 million fry per year come from this source. Estimates placed the number of hatcheries at 30 to 40 but one correspondent stated that only 11 hatcheries were actually operating in 1999. The cost of PL in 1999 was US$ 20 to 30/1000, more than twice what is was a decade earlier. Costs for 1999 for 5.0 to 7.5 cm juveniles were US$ 60 to 100/1000. Hatcheries obtain their broodstock from tidal rivers, beels, grow-out ponds and floodplains, and have capacities much larger than actual production. Although *M. rosenbergii* is indigenous, some stocks were introduced from Thailand in the early 1990s, so there has been some interaction between different strains. Hatchery tanks are stocked at 40 to 50/L in clearwater systems. Both flow-through and recirculation hatcheries exist; 70 to 80% are situated inland. The inland hatcheries use brine. Several hatcheries are operated by non-governmental organisations (NGOs). Lack of hatchery-reared PL remains a constraining factor to further development of this national sector. The other major problems in Bangladesh are natural disasters, particularly severe flooding.

The use of nursery-reared large (5–7.5 cm) juveniles for stocking grow-out ponds is being encouraged in the current expansion programme for 'gher' culture (see below), because of their better growth and survival characteristics. Push-netting, while being a valuable source of employment, has a high environmental cost. One estimate is that over 1000 other organisms are discarded for every *Macrobrachium* juvenile caught. However, in 1999, wild-caught PL were cheaper than hatchery-reared animals and most of the small hatcheries were not operational. With demand and prices increasing and capture fisheries supply dwindling due to overexploitation, it is expected that many hatcheries will come on-stream within the next few years.

Over 11 500 ha of water surface area is used for monoculture and nearly 11 000 ha for polyculture. Production systems include extensive, improved extensive, semi-intensive, mixed culture with carps, and integration with rice farming ('gher' farming). Where ponds are used, sizes range from less than 0.1 ha to 0.6 ha. It is estimated that over 5000 ha of ponds are devoted to monoculture in three districts of Bagerhat alone, but the level of technology is low. Some farms, associated with various projects, use a continuous cropping system.

Most prawn culture takes place in low-lying rice fields. Paddy fields of 0.2 to 0.8 ha ('ghers') are modified by the excavation of 1.0 to 1.8 m deep, 2 to 10 m wide ditches inside the periphery of the dykes. Culture starts with the introduction of 3.0 to 3.7/m^2 of wild-caught PL (it is interesting to note that these are preferred over hatchery-reared animals) as soon as they are available (April–June). The prawns spread into the whole 'gher' with the onset of the monsoon. Continuous cull-harvesting occurs. The grow-out season in this form of culture lasts from then until the following January, when the remaining prawns are harvested from the peripheral ditches. Meat of the snail *Pila globosa* (cost US$ 0.13–0.17/kg) is fed at the rate of 59 to 74 kg/ha but, due to the shortage of snails, some farmers use a farm-made mixture of fish meal, rice bran and oilseed cake (1:1:1), which costs about US$ 250/t. Some also supplement farm-made feeds with commercial feeds (US$ 500–600/t). Urea, triple superphosphate (2:1), and sometimes cow manure, are used for fertilisation by some farmers. Typically, 0.2 to 0.3 t/ha of prawns are obtained, the favoured harvest size being 100 g. Finfish, mainly silver carp, are also stocked at 2000/ha and produce a crop of about 2 t/ha. Some Indian carps (mrigal and rohu) are also introduced for home consumption. Freshwater prawns are cultured in most areas of Bangladesh, including Khulna, Bagerhat, Satkira, Mymensing, Jessore, Noakhali and Barisal. Diseases are not serious problems; however, black spots and 'fragile appendages' are observed. These are believed to be symptoms of poor management, which is a consequence of poor water supply and drainage facilities. The major problem is the inadequate supply of PL and juveniles, particularly in the first half of the year. Year-round availability of both fry and water would enable substantially increased national production.

About 60 to 80% of the freshwater prawns harvested are estimated to be sold to processors through middle-men, with a small quantity being sold farm-gate and in local markets. Estimates of the proportion of the farmed production which is currently (1999) exported range from 70 to 98%. Exports are mostly head-on, to the EU, Hong Kong, Japan and the USA. Most of the exported animals originate from 'gher' culture.

17.1.2 China

Though *M. rosenbergii* were first introduced into China in 1976 from Japan and first bred there in 1977, farming activities were minimal for the following 10 years. However, interest in culturing this species was stimulated following the severe decline in Chinese marine shrimp production which occurred in the early 1990s. The production of *Penaeus (Fenneropenaeus) chinensis* fell from a peak of 220 000 t in 1991 to 88 000 t in 1993 and 64 000 t in 1994; though production is recovering, in 1998 it was still only about 65% of the 1991 level. Farmed production of *M. rosenbergii* was not recorded separately in returns for FAO statistical data until 1996, when China first reported an output of over 37 000 t. Output rose to nearly 43 000 t in 1997 and nearly 62 000 t in 1998. Though no FAO data exist prior to 1996, other estimates show that production expanded very rapidly, from under 4000 t in 1993 to over 14 000 t in 1994. By 1995 it had increased to nearly 27 000 t. Production was therefore more than fifteen times greater in 1998 than in 1993, a meteoric increase which established China as by far the major freshwater prawn farming country at the end of the 1990s. One correspondent estimated that production fell slightly in 1999, caused by a decline in demand (all production is sold within China) and product value, due to the sluggish Chinese economy of 1998–1999. However, the industry was fully expected to take off again as the economy recovers. Further substantial expansion is expected.

More than half of the farmed production of *M. rosenbergii* was reared in Guangdong province in 1997. Other major rearing areas include the provinces of Jiangsu, Shanghai, Zhejiang, Anhui, Hubei, Guangxi, and Fujian. It is estimated that about 60% of the national production comes from monoculture and almost all the rest from polyculture. There is also some cultivation integrated with crop production. Most culture occurs in freshwater but some rearing in brackishwater (in areas of saline/alkaline soil, at 2–3 p.p.t.) also occurs. Some prawns are reared in the colder areas of China in hot spring waters. Some 50 to 70% of *M. rosenbergii* farms are less than 1 ha in area; only 5 to 10% are over 5 ha.

The expansion of farming was so rapid that PL had to be imported. It has been reported that over 200 million PL/yr were brought in from Thailand in the period 1993–1996. Nowadays, local supply is reported to be adequate, or exceeding demand. Farms now usually obtain *M. rosenbergii* PL from local hatcheries, sometimes operating their own, but also (rarely) from hatcheries in other areas of China. Estimates of the numbers of hatcheries vary wildly (from 20 to 250), as do the estimates of typical hatchery capacity (10 million/yr to 800 million/yr); some hatcheries also produce marine shrimp and crabs. These differences are probably because there are a number of large commercial hatcheries but also many small backyard hatcheries, as in Thailand. Total seed production is estimated to have reached 6 to 10 billion/yr (6–10 thousand million) by 1999.

Broodstock are brought indoors as soon as the temperature falls to 18°C. They are overwintered at 20 to 22°C at a 3–4 : 1 female : male ratio in 50 m^3 concrete tanks. The peak hatchery activity is in April. Larval stocking rates are up to 100/m^3 and the systems are mainly clearwater; most operate flow-through systems but, depending on location, some use recirculation. About 80 to 90% of the hatcheries are inland. The average price paid by farmers for PL in 1999 was US$ 23/1000. Prices for 2 to 3 cm juveniles were US$ 115/1000. The high costs of PL and juveniles reflect the necessity to overwinter broodstock in heated facilities and to operate heated nurseries to maximise grow-out time. Genetic degradation, in the form of earlier maturation, smaller adult size, and weakened disease resistance has been observed. This is thought to be the result of the inbreeding that has occurred since the first introductions from Japan in 1976 but the problem is being ameliorated by further introductions. Some mass mortalities of stage V and stage IX–X larvae (related to a combination of water quality, feeds and disease) have been reported. 'White prawn disease' or 'white muscle disease' has been reported in grow-out animals and some losses have occurred in overwintered broodstock.

Most farms obtain juveniles from specialist nurseries; some farms operate their own. Postlarvae are stocked into nurseries at 300 to 4000/m^3, often in 20 to 30 m^3 cement tanks for up to 1 month. These tanks may be covered so that the cycle can be started earlier to allow juveniles to be stocked into grow-out ponds at the earliest opportunity, as soon as temperatures are satisfactory. There is also some rearing of juveniles in 10 to 40 m^2 cages (0.8–1.0 m deep), stocked at 1500 to 3000/m^2, depending on water exchange. Juveniles of 2 to 3 cm are obtained within 1 month.

Grow-out ponds vary from 0.3 to 1.0 ha and may be rectangular or square; stocking densities range from 5 to 23 PL/m^2. Except for the province of Hainan, the growing period is restricted to 120 to 170 days/yr. Stocking occurs when the water temperature rises above 20°C. It is estimated that 60% of production is accounted for by monoculture (typical annual yield 2.25–3.00 t/ha). However, some farms are reported to stock at 45 to 65/m^2 and achieve production rates of 6 to 7 t/ha.

Most of the rest of the national production comes from two levels of polyculture. In the first system, where prawns are the primary crop, they are reared with silver and bighead carps (typically producing 1.2–1.8 t/ha/crop of prawns and 0.75–1.5 t of fish). Both farm-made (comprising trash fish, shellfish, snails, earthworms, and high protein animal and vegetable concentrates, fed individually or in formulated diets) and commercial feeds are used. The latter were reported to cost US$ 300 to 500/t in 1999 and to achieve a feed conversion ratio (FCR) of 2.0–2.3 : 1. Feeding rates are 5 to 7% of body weight. Organic fertilisers are used, usually chicken manure applied at 2 t/ha before stocking. In the second system, where finfish are the primary crop, prawns are stocked at a lower rate and production is typically 0.3 to 0.9 t/ha/crop of prawns and 5.25 to 7.5 t of fish.

A small amount of rice-paddy production also occurs, realising about 0.15 to 0.40 t/ha/crop and increasing income by US$ 600 to 1000/ha. In the late 1990s, the culture of *M. rosenbergii* in pens and cages (1.2–1.5 m deep and 15–20 m^2 in area) in lakes was introduced in China. The yield is 1.0 to 1.5 kg/m^2.

Most polyculture ponds are harvested once (batch culture), while those under monoculture are selectively culled five or six times before final harvesting. The harvest size is reported to be 40 to 60/kg (17–25 g). However, some of the output from those farms which have higher stocking and productivity rates must be of quite small prawns. This is unlikely to be a problem, since consumers find the smaller *M. nipponense* acceptable (see below). Usually the 'down-time' for ponds (dry) is about 4 months.

About 95% of the harvest is sold to wholesalers, the rest being sold farm-gate. The whole national production currently (1999) is destined for the domestic market. By 1995, the farming of *M. rosenbergii* had become one of the major high-value cultured freshwater species in China. Marketing is rather centralised, through middle-men. Frozen prawns are not favoured. Batches of 500 to 600 kg of live prawns are often successfully air-freighted from Guangdong to Shanghai and other cities.

China also produces very significant quantities of another much smaller, but more temperate, freshwater prawn species, namely *M. nipponense* (see Chapter 21); this category of aquaculture production does not yet appear in the FAO data. The province of Jiangsu is the main grow-out area but farming has spread to the lower reaches of the Rivers Yangtze and Pearl. One report is that 15 000 t of *M. nipponense* were produced in a total area of 50 000 ha in 1998; another is that production of this species may even have exceeded that of *M. rosenbergii*! *Macrobrachium nipponense* is favoured mainly because of its temperature tolerance and consumer desirability.

17.1.3 India

According to the most recent statistical returns made to the FAO, Indian production of *M. rosenbergii* (since first recorded in 1989) fluctuated wildly between 1989 and 1996 with lows of 150 t (1989) and 178 t (1993 and 1996) and a high of 455 t (1992). However, the picture is confused because, in the FAO aquaculture production statistics for 1984–1993 (published in 1995), a national production of 2000 t for 1992 and 3835 t for 1993 was recorded. By the following year (1996), the FAO published revised data showing 455 t and 178 t for 1992 and 1993, respectively. This discrepancy was clearly not simply an error of order of magnitude. A recent MPEDA (Marine Products Export Development Authority) estimate states that total farmed 'scampi' production in the 1997–1998 season (financial year to 31 March 1998) was 4904 t (of which 90% were estimated to be *M. rosenbergii* and 10% *M. malcolmsonii*). However, the most recent FAO figure (for 1998) shows only 1507 t for *M. rosenbergii*. Since MPEDA is responsible for providing subsidies and technical assistance to this export-oriented sector, its estimates may be accurate. This, and consideration of the area under cultivation (10 000 ha), indicate that the MPEDA figure may even be an underestimate, thus making it possible that the true production of farmed *M. rosenbergii* in India had exceeded 5000 t/yr by 1999.

Interest in freshwater prawn farming is strong and increasing because of virus disease problems in marine shrimp (the expectation is that prawns, reared at lower densities, will be less susceptible), environmental and social objections to marine shrimp farming, and the higher income per unit area obtainable from freshwater prawn production than from rice or other agricultural crops. One prediction is that Indian farmed production of *M. rosenbergii* will be at least 10 000 t/yr by 2004. However, some difficulties need to be overcome, including: policy, extension and training issues; technical difficulties (e.g. heterogenous growth rate); the high price of seed (more hatcheries are required); and inadequate marketing.

Postlarvae and juveniles are obtained from two sources: wild-caught and hatcheries. Grow-out farms pay US$ 9.8 to 14.3/1000 for PL and US$ 20.0 to 20.4/1000 for juveniles. A major problem with using wild-caught seed is that it includes many less commercially important *Macrobrachium* spp., and contains animals of differing size and age groups. It is estimated that there are about 16 medium-sized hatcheries for *M. rosenbergii* in India in 1999 (two of which are run by the government sector), as well as at least six 'backyard' hatcheries. It has been estimated that total national PL production may have reached 250 million/yr, with backyard hatcheries having a typical capacity of 2 million/yr and medium-sized hatcheries of 5 to 10 million/yr. Hatchery broodstock are obtained either from grow-out ponds or from the upper reaches of rivers. The management system is typically clearwater and flow-through, stocked at 40 to 50/L. About 50% of the hatcheries are inland, which implies that seawater or brine is trucked in.

Freshwater prawn grow-out occurs in both freshwater and, in tidal areas and depending on the monsoon, brackishwater. Estimates are that 80% is produced in freshwater. The culture systems include both monoculture and polyculture in ponds, mainly with Indian major carps – catla (*Catla catla*), rohu (*Labeo rohita*) and mrigal (*Cirrhinus mrigala*) – and silver carp, in 0.1 to 2.0 ha rectangular or square ponds. It has been estimated that there were over 600 farms growing freshwater prawns in 1999, with a total pond area of nearly 10 000 ha. The major growing areas were Andhra Pradesh (51%) and West Bengal (36%), with significant areas under cultivation in Orissa, Gujarat, Kerala, Maharashtra, Karnataka and Tamil Nadu. Some farms operate their own nurseries. Production also occurs in irrigation canals and integrated with rice production. Currently (1999), it is estimated that about 70 to 80% of national production comes from polyculture. Few farms are >5 ha; most farms are small (<1 ha) and are often a side activity of farms which are primarily agricultural. Annual productivity is at a semi-intensive level, namely up to 0.5 to 1.5 t/ha in monoculture and 0.2 to 0.5 t/ha in polyculture.

Grow-out stocking densities range from 0.5 to 2.5/m^2 in polyculture and 1 to 5/m^2 in monoculture. Inorganic fertilisers (e.g. urea, single superphosphate) are utilised to develop a plankton bloom, in addition to semi-dry cow dung and poultry manure, normally only at the time of pond preparation. The culture period is 6 to 8 months, starting at the beginning of the southwest monsoon season (May). Both moist farm-made (US$ 238–358/t) and commercial feeds (US$ 475–715/t, with an FCR of 2:1 claimed) are used, spread around the pond periphery at rates typically ranging from 10 to 3% of total biomass/day. Most farmers used (in 1999) farm-made feeds.

Harvesting is a combination of selective harvesting and seining (drag netting) before drain-down, followed by hand collection. The favoured market size is 50 to 120 g. It is estimated that most of the output (85%) of farmed *M. rosenbergii* in India goes to processors (virtually all destined for export), while small quantities go to local (2%) and non-local (5%) retail markets, wholesalers (4%), and hotels and restaurants (3%), or is sold at the farm gate (1%). Farmed prawns are exported by India to the USA and the EU, with a little to Japan.

In 1997 it was reported that, following the work of the Madhya Pradesh Fisheries Development Corporation, which achieved 1.2 t/ha and prawns in the size range 70 to 200 g within 6 months, the Central Bank of India had agreed to finance five commercial farms. A constraint was the supply of good-quality fry, which were then being obtained from Andhra Pradesh at US$ 27/1000.

17.1.4 Malaysia

Freshwater prawn farming has a special significance for Malaysia, where Shao-Wen Ling's pioneer studies were made (see Chapter 1). Interest was strong in the late 1970s and the 1980s, when developments included a 40 ha farm in Selangor and a model hatchery in Melaka, but the volume of production from commercial farming has been modest and very variable. FAO statistics during the period 1984–1997 showed peaks of 145 t in 1991 and 143 t in 1997 and lows of 46 t in 1994 and only 5 t in 1987. However, the latest official data show a production of 281 t in 1998. This conforms with unofficial estimates obtained during the production of this book, namely that production was about 200 to 280 t/yr in 1998, mostly in the states of Perak, Negri Sembilan, Selangor, Pahang, Malacca and Johor. Most existing farms are small; about 70 to 75% are estimated to be less than 2 ha. The national aquaculture emphasis has been on marine shrimp farming but the problems in that sector were reported to be turning investors' attention towards *Macrobrachium* again as the 1990s came to an end and the economy began to take an upturn.

Production is expected to increase, judged by the increased demand for PL and juveniles and the number of new and expanded farms (e.g. 20 ha in Selangor and 60 ha in Negri Sembilan). The high prices achieved for prawns is turning farmers' attention away from finfish. Recently (1999), a large (1200 ha) eel farm in Pahang that has been facing difficulties in obtaining sufficient elvers, has decided to convert some of its ponds to freshwater prawn culture. Other favourable factors include the more ready availability of commercial aquafeeds in Malaysia, together with increasing support from government, university and private sectors (national farmers associations).

Grow-out farms obtain all their stock from hatcheries. About 50% of the hatcheries are owned by grow-out farmers and sell 20% of their fry to others. Some 70 to 80% of the PL stocked by farmers come from local hatcheries and 5 to 20% from hatcheries located in other parts of Malaysia. There are estimated to be 20 to 25 Malaysian hatcheries with a wide range of capacity (1–10 million PL/yr) but 15 to 20% of the PL supply is believed to come from Thailand. It is interesting to note that, contrary to most countries, 80% of the broodstock used by Malaysian hatcheries are reported to come from rivers; 20% come from grow-out ponds, from which the largest berried females are selected. Farmers are said to believe that PL from Malaysian hatcheries have better growth and survival rates than those from Thailand (this contrasts with the farmers' views in Taiwan [section 17.1.5]), which are imported only when there are local PL shortages. Again, contrary to most countries, many Malaysian freshwater prawn hatcheries operate a greenwater system with some water exchange. Most (80–95%) hatcheries are located inland. Larvae are stocked at 30 to 60/L.

There are no specialist nurseries. Farmers generally rear PL to 11 to 13 mm juveniles in their own nursery ponds, stocked at 600 PL/m^2, or in hapas (net cages) stocked at 450 to 1000 PL/m^2 and situated within grow-out ponds. The juveniles are graded after 2 months for transfer, according to size, to grow-out ponds, where the stocking rate is 10 to 15/m^2. In 1999, PL cost about US$ 13 to 16/1000, rather more expensive than a decade ago. All current production occurs in ponds, although there has been some experimental culture in canals. Ponds are typically less than 0.2 ha; their shape is mainly rectangular (98%), while the rest are irregular in shape. Some farms use simple farm-made feeds incorporating tapioca, copra, chicken viscera and other ingredients, while others use commercial feeds which typically cost US$ 580 to 660/t (1999) and achieve FCRs of 1.8–3.0 : 1. The major technical problem is seasonal water shortages in some areas. Between cycles, ponds are scraped, limed, fertilised, and teaseed cake applied. Poultry and cow manure, together with inorganic fertilisers (e.g. triple superphosphate and urea) are used. Inadequate fry supply and the encroachment of other developments which affect water quality are reported to have been problems. Some developmental work to encourage the integration of prawn culture with rice production is on-going (1999).

Most farms manage their harvesting by selective culling (marketable size is above 25 g) every 3 to 4 weeks, commencing 3.5 months after stocking, followed by draining after 5 to 6 months. Production rates of 0.90 to 3.15 t/ha/crop have been reported. It is estimated that most farms (70%) sell their production at the farm gate or to hotels and restaurants. While small quantities may be sold directly to retail markets in the locality and in other parts of the country, about 30% goes to wholesalers. Most prawns are consumed domestically, but 10 to 15% is exported. Live prawns go to Singapore, while processed prawns are now being exported to Japan by the eel farm mentioned above.

17.1.5 Taiwan

Taiwan has a long history of commercial freshwater prawn culture. The major area where freshwater prawns are cultured is in the northern part of Pingtung county (southwest Taiwan). National production showed rapid expansion from around 4300 t in 1988 to a peak of over 16 000 t in 1991. The incentive to operate this form of aquaculture was high, partly because of a concurrent huge decline in the farmed production of marine shrimp, due to disease and water quality problems. However, the production of *M. rosenbergii* has also declined, falling by more than 50% in 1992, compared to 1991, mainly because of disease problems (see Chapter 15). Production fell further to a low of just under 5500 t in 1993. Since then, according to FAO statistics, national production has recovered somewhat but annual production in 1998 was still only 50% of the peak output of 1991. Despite production having halved from its summit, Taiwan remains one of the top six freshwater prawn producers globally, the others being China, Bangladesh, Thailand, Vietnam, and India. Local experts believe that Taiwanese production may decline again, due to high production costs, the depletion of underground water resources, and the marketing status of prawns. In addition, while yeast infections have previously been experienced in the winter during periods of low temperature, bacterial infections are also being observed in the summer now. However, difficulties in importing freshwater prawns from mainland China currently ensure the survival of this type of aquaculture in Taiwan.

Most farmers do not have their own hatcheries. There are about 20 inland hatcheries and a further 30 which have been converted from marine shrimp production in coastal areas. Competition is intense: coastal hatcheries have lower production costs but inland hatcheries have the advantage of being closer to their market. Average hatchery production of *M. rosenbergii* PL is 10 million/yr. As in Thailand, some of the hatcheries produce both marine shrimp and freshwater prawn PL sequentially, according to market demand. Freshwater prawn PL production tends to be seasonal (March–April and September–November) and it is difficult for hatcheries to survive unless they can produce other species as well. Recently (1999), many hatcheries have closed, due to low survival rates and high production costs. Hatcheries buy their broodstock from brokers, who collect them from grow-out farms. A flow-through clearwater rearing system is favoured by most hatchery operators, stocked at 80/L. The water is enriched with prawn flakes.

Locally produced PL are used by grow-out farmers but a large quantity of PL are also imported from Thailand (800 million in 1998). Thai PL have a reputation for better disease resistance and faster growth rate during grow-out (this contrasts with the perception in Malaysia [section 17.1.4]). Many farmers have their own nursery pond(s), which are used for overwintering PL to produce juveniles for stocking in the spring to lengthen the grow-out period; thus the market for PL that exists in the autumn. Small farmers have little choice but to purchase their juveniles for this purpose. Currently (1999), PL prices range from US$ 1.9 to 6.3/1000, with a mean of US$ 4.7/1000. Ten years previously, PL prices ranged from US$ 12.5 to 25/1000.

A three-stage production cycle is employed. Firstly, PL are stocked at 150 to 200/m^2 and reared to a 3 g size; secondly, these are stocked at 40 to 50/m^2 to 6 g. Finally, 6 g prawns are stocked at 15 to 20/m^2 with the aim of achieving a 30 g market size. Overwintered juveniles currently (1999) cost US$ 6.8 to 8.3 for the 3 g size and US$ 8.3 to 9.4 for the 6 g size.

Nearly all production comes from monoculture, with only 20 to 60 t/yr from polyculture. Some 95% comes from freshwater and the rest utilises water of around 5 p.p.t. Typically, farms are moderately sized, between 1.0 and 2.0 ha and family operated; 60% of the farms are of that size, with 20% larger and 20% smaller. Pond size is typically 0.25 to 0.5 ha, usually rectangular in shape. Most feeds are commercially produced and, though very expensive (US$ 1064/t) compared to most countries, achieve an apparent FCR of 1.8 : 1. Rice bran, chemical fertilisers, bone powder and 'some biochemicals' are also added to the ponds. The grow-out ponds are harvested by continuous culling, normally at 1-month intervals but primarily according to market demand. Mean production rates are said to have fallen from 3 to 2 t/ha due to the disease problems noted above.

Most of the output from Taiwanese freshwater prawn farms is sold live to wholesalers. *Macrobrachium rosenbergii* is mainly consumed locally, as a result of recreational fishing activities from ponds. The value of this product is therefore particularly dependent on the general status of the national economy. This business is also depressed in winter due to the poor appetite of prawns at lower water temperatures. There is no export of freshwater prawns from Taiwan. High production costs (particularly due to the cost of *Artemia* and the labour involved in grading and intermittent harvesting), foreign competition in PL supplies, poor survival and growth rates during the grow-out period (partly said to be caused by inbreeding and more evident when locally produced PL are used), and the overuse of underground water, all contribute to the forecast that prawn farming in Taiwan may decline further. Production is expected to stabilise at a lower level. However, any change in the ability to import live prawns from mainland China would have a profound impact upon the market.

17.1.6 Thailand

The farming of freshwater prawns in Thailand began a little earlier (in the mid-1970s) than in Taiwan but production was small until the co-operative efforts of the Thai Department of Fisheries and the FAO in 1979–1981 stimulated expansion, both in this country and, by diffusion and the provision of expertise, in many others. Production, less than 5 t in 1976, had expanded to an estimated 400 t in 1981. By the time the first global aquaculture statistics were published by the FAO in 1989 it became clear that Thai production of freshwater prawns had exceeded 3000 t by 1984. Since then, the data on farmed *M. rosenbergii* production in Thailand reported to the FAO have been subject to a number of retrospective adjustments. However, according to the statistics published in 2000, production averaged about 8300 t/yr during the decade between 1989 and 1998, with peaks in 1992 (10 306 t) and 1994 (10 124 t). Production never quite reached the peak achieved by Taiwan in 1991 (see section 17.1.5) but the average for the decade (1989–1998) was similar. The most recent FAO statistics reported production of 7800 t in 1998.

The volatility of annual production in Thailand has not been due to the technical problems experienced in Taiwan but to marketing and economic factors. One of the features of both freshwater aquaculture farms and hatcheries in Thailand has been the ability to react rapidly to changing demand. Thus, hatcheries are not confined to a single species but produce the one in current demand, be it marine shrimp, sea bass or freshwater prawns. Demand for freshwater prawn PL depends largely on the market for rice and freshwater finfish, and grow-out farmers are similarly flexible enough to adjust to the prevailing market for each commodity. Predictions about the future vary. On the one hand new ponds are unlikely to be dug because land is expensive. On the other hand, freshwater prawn production is expected to increase because of two factors. The first is that local demand for this traditionally popular food item is rising, following recovery from the economic crisis of the mid-1990s. Secondly, the farming of marine shrimp, on inland sites (where freshwater prawn farming was once practised), which had been expanding rapidly, has been banned for environmental reasons. The effect of these two factors is expected to be that farmers will revert to *Macrobrachium* culture in many existing finfish and inland marine shrimp ponds. One correspondent therefore estimated that annual production may have risen to 12 000 t in 1999. Most of the grow-out occurs in the central floodplain area of Thailand (notably Nakhorn Pathom, Supanburi and Ratchaburi provinces); consequently, it all takes place in totally freshwater. Most farms are quite small (95% less than 2 ha) and very few are larger than 5 ha.

Many of the commercial hatcheries (perhaps 50%) are integrated with grow-out farms on inland sites. Another 40% of the PL supply comes from other hatcheries local to the primary grow-out area (and therefore also inland), while less than 10% come from coastal sites, mainly in the brackishwater areas of Chacheongsao province, adjacent to the fisheries station principally responsible for the birth of commercial prawn farming in Thailand. Now that there are plenty of commercial hatcheries, the government hatcheries that stimulated the development of farming are devoted to supplying the demand for re-stocking programmes (see Chapter 22). Estimates of the number of hatcheries producing freshwater prawns in 1999 vary from 100 to 300. This wide range stems from the multi-purpose nature of Thai hatcheries discussed above. Total national production of PL in 1999 was estimated to be 5 billion/yr (5000 million/yr); some of this production is exported (e.g. see sections 17.1.2, 17.1.4 and 17.1.5). This level of reported production is similar to that produced by the freshwater prawn hatcheries of China (section 17.1.2), which may imply that the scale of fisheries enhancement activities may be larger than indicated in Chapter 22 and/or that export activities are substantial.

Hatchery broodstock are obtained from grow-out ponds and the hatcheries operate clearwater systems, stocking at between 30 and 100/L. Some use daily water exchange but many variations on the standard technology exist to reduce the cost of transporting brine to inland hatcheries. These include using freshwater (instead of brackishwater) for replacement (resulting in a gradual decline in rearing salinity); some hatcheries use biofilters to conserve water use. Some PL are reared in earthen ponds instead of hatcheries (see Chapter 5). In 1999, PL were being sold at US$ 1.38/1000, a price which had remained steady for 10 years and which was substantially lower than in most, if not all, other countries.

There are no specialist nurseries for *M. rosenbergii* in Thailand but an increasing number of farms rear PL to juvenile size in their own nursery facilities, stocking at up to 125/m^2, aerating by paddlewheel, and achieving 50% survival over several months before transfer. Almost all grow-out production originates from ponds, typically stocked at 10/m^2, but there is also some from the irrigation canals surrounding crop plantations. Most ponds are rectangular and vary from 0.5 to 1.6 ha in area. In 1999 it was estimated that about 50% of the feed was still farm-made but commercial feeds were becoming more popular. Many farms use a combination of farm-made and bought-in feeds. The commercial feeds achieve an FCR of 1.75–1.2 : 1 and cost (1999) US$ 555/t. Ponds are limed during pond preparation and chicken manure may be used to provide an initial plankton bloom. Some farms which use the technology developed for intensive marine farming, including paddlewheel aeration, achieve over 3.1 t/ha/crop. Most of the problems experienced concern seasonal and local water shortages, and poor water quality (especially sudden changes in pH following heavy rain, early morning plankton-induced oxygen depletion, and a build-up of dissolved nitrogen compounds and hydrogen sulphide in pond sediments). Few disease problems are noticed, except for protozoan-induced black gill disease. Management problems, such as the wide size range of harvested animals, still exist.

Typically, ponds are no longer operated on a continuous basis. A series of selective harvests (Plate 5, facing p. 220) are taken before the ponds are finally drained, after about 11 to 12 months, depending on the availability of water. Female prawns are culled out and sold about 3 to 4 months after stocking, following which monthly selective harvesting is practised over a further 6 to 7 months. Draining and pond drying usually takes place in May, before the onset of the new rainy season. The harvest is sold by a wide variety of means: farm gate, to restaurants and hotels, to local and distant retail markets, and to wholesalers. Animals are often transported live to restaurants and hotels but most prawns sold in markets are displayed fresh on ice. Some of the production goes to processors for export.

Thai Department of Fisheries statistics (Table 17.1) indicate that Italy and France were substantial importers of Thai head-on freshwater prawns in 1998, while the major importers of head-off prawns were the UK and Belgium. Between 1996 and 1998, an increasing trend in the import of Thai head-off freshwater prawns was observed, particularly by the UK and Belgium, although imports of head-on prawns were extremely variable. In 1998, Thailand exported a total of 441 t of head-off and 674 t of head-on freshwater prawns. It is difficult to know what proportion of these prawns were from Thai farms, because Thailand also imports freshwater prawns, notably from Bangladesh, for processing and re-export. Import statistics do not

Table 17.1 Export of Thai freshwater prawns (*Macrobrachium rosenbergii*) in metric tons, 1996–98.

Type of product	Export destination	1996	1997	1998
Frozen head-off	UK	27.2	105.9	238.5
	Belgium	25.3	45.7	111.2
	Netherlands	24.0	25.3	42.2
	Germany	10.4	–	37.7
	Norway	–	–	7.5
	France	–	13.0	4.0
	Singapore	–	32.7	–
	Cyprus	5.9	2.4	–
	New Zealand	–	1.3	–
	Italy	4.9	–	–
	Japan	4.6	–	–
	Switzerland	0.8	–	–
	Australia	–	0.4	–
	USA	32.1	–	–
	Totals	135.2	226.7	441.1
Frozen head-on	Italy	1033.3	346.0	258.7
	France	142.7	71.0	206.0
	Réunion	380.1	92.6	67.8
	Netherlands	–	–	43.7
	Belgium	–	8.0	35.9
	South Africa	34.7	16.2	27.9
	Germany	28.1	15.6	17.2
	Iceland	–	–	8.4
	UK	–	19.8	4.1
	Hong Kong	–	3.1	2.5
	New Zealand	22.6	3.8	1.8
	USA	–	7.6	–
	Sweden	–	0.6	–
	Totals	1641.5	584.3	674.0

normally distinguish marine shrimp from freshwater prawns. Some large, wild-caught (and therefore larger) prawns are also brought across the borders with Myanmar and (less so) from Cambodia, but it is likely that these are consumed domestically.

17.1.7 Vietnam

Freshwater prawn farming began in the early 1980s in Vietnam, to supplement the capture fisheries production. The scale of farming activities is now substantial but it is difficult to assess the volume of its national production. No specific figures for farmed *M. rosenbergii* production appear in FAO statistics but there is a general category of estimated production named 'freshwater crustaceans not elsewhere included' which rose fairly steadily from 5000 t in 1984 to over 25 000 t in 1998. The remaining question is: how much of this estimated production is freshwater prawns? Recent estimates, obtained during the preparation of this book, indicate that the production of farmed freshwater prawns in the Mekong delta region, the main farming area, rose from 2500 t in 1995 to 3000 t in 1998 and was still expanding in 1999. The details of farming which follow apply to activities in the Mekong delta region. This region has an area of more than 4 million ha, of which nearly one-quarter consists of water surface, in addition to the rivers themselves. About 67% of the water areas are freshwater. *Macrobrachium rosenbergii* is indigenous in the delta, mainly in its central portion.

Less than 10% of production is estimated to come from monoculture. Around 30% comes from polyculture with common carp, tilapia and silver barbs. The bulk (about 60%) is produced in integrated systems, mostly with crops (sometimes referred to as garden–prawn or orchard–prawn culture). Ponds, rice paddies, and garden (crop production) ditches are utilised. About 4000 farms are reported to exist, 60% of which are smaller than 1 ha. Only 5% are said to be more than 5 ha. Prawn farming is expected to expand very significantly in the future because of several factors. The farmed area is expected to rise and will not be confined to existing areas with freshwater supplies. Many of the brackishwater areas previously used for marine shrimp culture have been converted to agricultural use and therefore are becoming available for prawn culture as well. Prawn farming provides an opportunity for agricultural crop farmers to increase income and the government is promoting the sector.

Most PL and juveniles for stocking grow-out areas still come from the capture fisheries, where brushwood (Fig. 17.1), stow and straw nets, and shelter traps are commonly used. Many hatcheries are under construction. About 15 already exist but the PL supply is not yet stable. The capacity of the five national hatcheries ranges from 2 to 5 million PL/yr. About 10% of the hatcheries use a static water greenwater system. Some 90% of the hatcheries are inland; these tend to use recirculation through biological filters. Other hatcheries operate a flow-though clearwater system, because of the difficulties experienced with greenwater (algal culture; environmental control; disease problems) and recirculation (high technological demands) systems. The problems experienced with recirculation systems may reflect the sophistication of the systems originally introduced into Vietnam. Modern recirculation systems used in prawn hatcheries in other countries, notably Brazil, are relatively simple to operate.

No hatcheries integrated with farms were reported. Stocking rates in Vietnamese hatcheries vary from 50 to 150/L. Hatcheries prefer to use wild-caught broodstock, which are supplied by fishermen and middle-men. However, this resource is becoming over-exploited, so some broodstock from grow-out ponds are also used. The early mat-

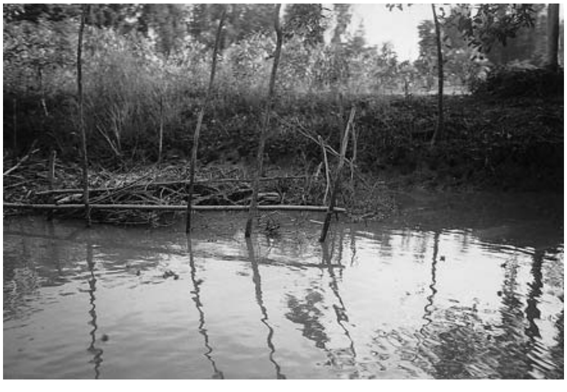

Fig. 17.1 Brushwood used to collect postlarvae (PL) of *Macrobrachium rosenbergii* in Vietnam. (Source: Michael New.)

uration of females in grow-out ponds was cited as a problem. Some bacterial disease problems (*Vibrio* sp.) have been experienced in hatcheries. In 1999, hatchery-reared PL were US$ 7/1000, while 3 to 5 cm juveniles were available for US$ 20/1000. Some farmers operate their own nurseries while others purchase juveniles for grow-out stocking.

Typically, ponds and garden canals are stocked at 4 to 6 juveniles/m^2 and paddy fields at 0.5 to 2/m^2. Ponds are usually rectangular and small (0.1–0.2 ha), while rice fields are 0.5 to 2.0 ha, of which 15 to 20% consists of internal canals. In the paddies, the water level is 1.0 to 1.2 m in the canals and 0.2 to 0.6 m over the rice growing area (when flooded). Both farm-made and commercial feeds are used in ponds and, intermittently, in rice fields. Ponds have about 2 to 4 months down-time between crops, during which liming and predator eradication is practised. Urea and di-ammonium phosphate are used in rice fields. Monocultured pond productivity ranges from 0.60 to 0.75 t/ha. In polyculture, total production is 2.1 to 3.0 t/ha, of which about 10% is freshwater prawns, the rest being finfish: silver carp, silver barb, tilapia, river catfish, and common carp. The prawn productivity in rice fields is 0.1 to 0.3 t/ha/yr. Typically there are two rice crops per year but the prawn crop spans two rice crops; prawns remain in the irrigation ditches (or are temporarily transferred to an adjacent pond) during the first rice harvest and allowed back into the paddies for a total of 8 to 12 months rearing period. Further details about the polyculture and integrated forms of culture are given in Chapter 12.

Selective harvesting occurs several times before the final drain harvest. About 50% of the crop is sold to wholesalers, while the rest is sold by the farmers at local retail markets and at the farm gate, in roughly equal proportions. About 70% of production is exported, mainly to Europe.

The major constraints that need to be addressed to enable prawn culture development targets to be achieved in Vietnam include the scarcity of good-quality seed and feed supplies, and the necessity to enhance the technical capacity of farmers.

17.1.8 Other Asian countries

Research or small-scale activities have been reported in **Brunei Darussalam** but annual production never rose above 1 t from 1989–1998. Up to 1999, there were no freshwater prawn hatcheries or grow-out farming activities in **Cambodia** because the technology has not yet been adequately demonstrated. However, some potential may exist, since wild-caught *Macrobrachium* are sold domestically. Although there have been a number of attempts at stimulating the development of commercial freshwater prawn farming in **Indonesia** (e.g. in Bali in the mid-1990s), these have yet to bear fruit. No Indonesian production of farmed freshwater prawns is recorded in FAO statistics.

FAO statistics do not show any specific production of *M. rosenbergii* in **Japan**, although production of 'freshwater prawns and shrimps not elsewhere included (Palaemonidae)', was reported during the years 1989–1998. *Macrobrachium rosenbergii* is the only species commercially farmed. Using the FAO data, backed up by local information, it appears that production (which was 24 t in 1984) reached a peak of 55 t in 1987. However, output has since gradually declined and was only 12 t in 1997 and 14 t in 1998. Over these years freshwater prawn farming ventures have been intermittent and widely scattered throughout Japan, mostly selling to hotels and restaurants, but 50% of the 1997 production is reported to have come from the Osaka area. Though there are some imports of freshwater prawns into Japan, it is a small local niche market. Consumers generally prefer marine shrimp, especially *Penaeus* (*Marsupenaeus*) *japonicus*, which are consumed raw or cooked. Despite this, other species of *Macrobrachium*, mainly *M. nipponense,* are harvested from the capture fisheries of Japan (see Chapter 22).

Myanmar initiated work on the culture of *M. rosenbergii* in 1980, based on information gathered at a milestone conference (Giant Prawn 1980) held in Bangkok, Thailand. Further assistance was provided by a number of authorities and countries, including the Asian Development Bank, the FAO, Indonesia, Japan and Thailand. Farming, either in monoculture or in polyculture with carps, has been practised since 1981. However, reported national farmed production has remained low, ranging from 3 to 10 t/yr. In 1998, reported production was only 6 t but there is considerable potential for expansion. *Macrobrachium rosenbergii* is indigenous to Myanmar and prawns from its capture fisheries are traditionally found in the markets of Thailand.

Some interest has been shown in the culture of freshwater prawns in the land-locked country of **Nepal**, using PL introduced from India, but no production has been reported. Until recently, all research towards freshwater prawn farming in **Pakistan** was based on *M. malcomsonii*. However, in 1996, the FAO conducted a feasibility study on establishing a freshwater prawn hatchery in Sindh province based on *M. rosenbergii*. While encouraging the continuation of work on *M. malcolmsonii*, this study recommended that *M. rosenbergii* should be the species chosen for commercial development. No information about the follow-up to this study is available.

There is a substantial capture fisheries for freshwater prawns in the **Philippines** (see Chapter 22). Research and development activities, using foreign technology, occurred there many years ago; however, no farmed production has yet been reported. Recently, small numbers of PL have been provided to tilapia farmers and two farm reservoirs have been stocked. Currently (1999) a government hatchery is being constructed in Muñoz, Nueva Écija. When this hatchery is complete, it is anticipated that freshwater prawn farming will be practised by tilapia farmers, in either polyculture or monoculture. The production emphasis of these farms may ultimately veer towards *M. rosenbergii*, which commands a better price than tilapia in the Philippines. It is hoped that commercial hatcheries will begin to appear locally, once demand is stimulated by government extension activities. Should demand for PL exceed local supply initially, they can be obtained from Taiwan or Thailand. The detailed technology which will be utilised by commercial freshwater prawn hatcheries and grow-out facilities in the Philippines remains (in 1999) a matter of speculation. However, once PL become readily available, our correspondent predicts that this type of aquaculture will become substantial in volume. Freshwater prawns are expected to be cheaper than marine shrimp and therefore more available for low income domestic consumers.

Though experiments on the culture of *M. rosenbergii* took place in the 1970s in the stations of the Primary Production Department of **Singapore** (Rabanal 1979), commercial farming did not follow. The reasons were the limited space available, high costs, and the decision to concentrate efforts on offshore aquaculture as well as (at one moment) on the intensive culture of marine shrimp.

Though there has been experimental work, no commercial farming of *M. rosenbergii* was reported in **Sri Lanka** in 1999. However, new policies aimed at stimulating aquaculture development are expected to boost interest in the farming of this species.

In Western Asia, the main activity has been in **Israel**. Although FAO statistics show that production of freshwater prawns peaked in the mid-1980s at 25 t/yr, the actual production may have reached as high as 40 t/yr. By 1987 production had declined to 3 t/yr, where it remained until 1994. Since then there has been no reported production. The demise of this industry, in a technological climate where research achievements in this field have continued, is attributed to several factors. These include: the high cost of PL; the attractions of alternative crops like tilapia which are perceived to be less sensitive to low oxygen levels, easier to harvest and store before export; the absence of a sufficiently large local demand base (prawns are non kosher) which could have supported the development of an export sector; and poor marketing. Most prawns were harvested within a relatively short period (September–October) and mainly exported frozen. The small and seasonal nature of the harvest precluded the development of a reliable export market. Despite these constraints, several farmers who used to culture *Macrobrachium* have recently indicated an interest in starting again.

Preliminary activities have been reported in **Iran** but have not yet resulted in commercial production. In 1990, *M. rosenbergii* was introduced into a hatchery situated 400 km north of El-Aqaba, the only source of seawater in **Jordan** (recirculation systems do not seem to have been tried). Suitable sites for grow-out ponds were not identified; the pH of water in those that were established exceeded pH 9. This activity was abandoned in 1995. In **Saudi Arabia**, limited quantities of freshwater prawns were imported from Pakistan in 1984 by Saudi Fisheries (species unknown), but they did not prove successful with its clients when offered at prices higher than the locally favoured marine shrimp, *Penaeus (Fenneropenaeus) indicus*. Despite this, a feasibility study on freshwater prawn farming was conducted in 1994, and several pilot-scale projects have been reported in the Riyadh area. However, none has become commercial.

17.2 South America

Information on freshwater prawn farming in Brazil is provided in section 17.2.1. The other producing countries have been grouped in section 17.2.2.

17.2.1 Brazil

FAO data show that production of farmed *M. rosenbergii* in Brazil peaked at 700 t/yr in 1989, 1993 and 1994, but declined to 341 t in 1995. In the years 1996–1998, estimated production remained between 450 and 500 t/yr. These official figures may underestimate the true production, since there were hundreds (possibly thousands) of small farms scattered throughout the country during the late 1980s and early 1990s. However, whatever its exact scale, there has certainly been a considerable decline in national production. Most of the small farms have disappeared and a large farm in the Northeast (>50 ha) stopped activities in 1998. The main production area is in Espírito Santo State, in the Southeast. Almost all production is in freshwater. The normal management system is monoculture. Very small quantities of freshwater prawns are produced in polyculture (probably less than 10 t/yr) but there is potential for expansion if fish farmers can be convinced that the introduction of freshwater prawns using suitable management strategies would increase profits (see Chapter 12). In 1999, it was estimated that there are about 120 *M. rosenbergii* farms in Brazil. Nearly 40% are 1 to 2 ha in water surface area; about 28% are 2 to 5 ha and 25% are <1 ha. Only 10 farms are >5 ha. Again, these estimates are believed to be lower than reality, especially for the farms <1 ha.

The reasons for the decline in production are several. While demand from supermarkets is strong, the federal Government has ceased all assistance to the freshwater prawn (*M. rosenbergii*) farming sector and concentrated on incentives for marine shrimp, *Penaeus (Litopenaeus) vannamei*, culture. The cessation of production in the >50 ha farm in the Northeast, which was not caused by any difficulty in marketing (its 20 t/month production was easily sold), helped to create a negative investor climate. Unfounded rumours have been spread that: freshwater prawn farming is not profitable; that there is no market; that it is impossible to set up an industry based on small farmers; etc.

By 1999, despite the decline in production that had occurred, many individuals and local government agencies were showing increased interest in farming prawns in regions where it has not yet taken off, notably the Amazon. The basic problem is that, although excellent technology is available in Brazil, the methods for its extension are unsatisfactory. Many operators continue to use outdated techniques and many technicians are also 'out of date'. Espírito Santo State producers are strong and organised but have experienced many problems in PL supply. The result has been that some farmers abandoned prawns and an established market was lost. However, these producers are often cited as examples of a profitable industry, even though it is based on small farms; now (1999) the farmers' association has built a processing plant and is setting up its own high-technology closed-system hatchery. The future success (or failure) of the prawn farming industry in this State will have far-reaching effects on the whole national sector. Correspondents believe that national production will not decline any further; every effort is being made to improve the extension of sound technology. Whatever the future of *M. rosenbergii* farming, there is a strong interest in the farming of a smaller, but locally preferred species, *M. amazonicum* (see Chapters 21 and 22).

Currently (1999), about 75% of *M. rosenbergii* farms obtain their PL from local hatcheries, while the rest transport them from hatcheries in other areas. There are at least 10 large hatcheries and an unknown number of smaller ones. Of the 10 large hatcheries, one has a capacity of 20 million PL/yr, six are in the 8 to 10 million range, one has a capacity of 3.5 million and the remaining two have a 1.2 million PL/yr production capacity. Aquafarmers prefer to buy from large government or commercial hatcheries; there is no tradition of backyard hatcheries in Brazil. A few farms stock juveniles; amongst these, about half operate their own nursery systems but the rest obtain juveniles from specialist nurseries. Most hatcheries obtain their broodstock from grow-out ponds. A few maintain their own broodstock ponds but there is no selective breeding programme. The hatcheries operate clearwater systems; both flow-through and recirculation systems are practised. About 70% of the hatcheries are on inland sites. The typical larval stocking rate is 80 to 100/L.

Grow-out ponds (Fig. 17.2) are stocked at 5 to 10 PL or juveniles/m^2. Currently (1999), PL can be purchased for US$ 8 to 10/1000 but there have been large fluctuations over the past decade, according to supply and demand (US$ 2–25/1000). Similarly, while the current price for 0.3 to 0.4 g juveniles is US$ 15/1000, the 10-year range has been US$ 15 to 40/1000. It is difficult to provide a clear picture because of the huge changes in the value of the Brazilian currency during this period. Grow-out ponds are generally rectangular and from 0.1 to 0.5 ha. However, there are also many small farms with ponds between 0.05 and 0.1 ha. Very few farms use farm-made feeds. The cost range of commercial feeds is very wide (US$ 250–400/t). Typically, the FCR is 2.5 : 1. Poultry and cattle manure, together with ammonium sulphate and superphosphate are employed for fertilisation. The major technical problem throughout Brazilian freshwater prawn farming is currently (1999) poor PL availability. Some farmers complain about the high costs (and poor quality, especially in the North) of aquafeed, as well as a lack of technical support, difficulties in obtaining low-interest finance, and marketing problems. In the South, cold water temperatures constrain production, while water availability is poor in the Northeast. In the Southeast, land availability and high labour costs are a factor. No diseases are prevalent in grow-out in Brazil.

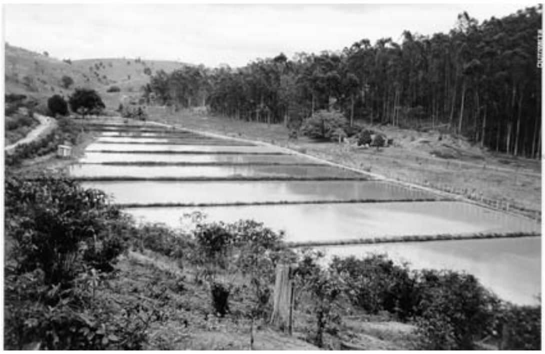

Fig. 17.2 Freshwater prawn (*Macrobrachium rosenbergii*) farm in Espírito Santo State, Brazil. (Source: Wagner Valenti. Courtesy of Joao Guilherme Centoducatte.)

The normal system of harvesting is a combination of selective culling, followed by drain-down at the end of the cycle. The down-time between production cycles is 3 to 4 months in the South and part of the Southeast (due to climatic factors) while it is about 20 days in other regions. During this period the bottom sediment is removed and the ponds are fertilised with manure, and limed when necessary. About 30% of the harvested prawns go directly to processors, while 15% are sold at the farm gate, 20% to restaurants and hotels, 20% in local retail markets, 5% to retail markets in other parts of the country and 10% to wholesalers. In the South there is also some limited door-to-door selling of freshwater prawns. All farmed prawns are consumed domestically; there is no export trade.

17.2.2 Other South American countries

The FAO first recorded production in **Argentina** in 1992. National production of between 20 and 22 t was reported for the 3 years 1996–1998. The pioneer is a company in the northeastern part of the country (Santa Ana, Corrientes), which also processes and markets indigenous finfish. It has an integral 700 m^2 prawn hatchery, a 2 t/hr aquafeed mill, and its own processing plant, as well as nursery and grow-out ponds. Prawn production was 2 t in 1994, and rose to 5 t in 1995, 7 t in 1996 and 11 t in 1997, 14 t were produced in 1998 and 15 t in 1999. Prawns are monocultured in ponds supplied from the Paraná River and by wellwater. Despite the high costs of land, labour, and credit, and the fact that aquaculture and fish consumption have little tradition in Argentina, both correspondents are up-beat about future expansion in this area, which has 7 to 8 months when temperatures are suitable for grow-out.

The Santa Ana farm in Argentina had 30 ha of ponds by 1999 and is being expanded to 50 ha. A selective breeding programme commenced in 1995. The farm uses covered broodstock ponds containing 10 000 adults of both sexes, which are fed a special diet and receive continuous water recirculation and aeration. Berried females are seined to supply the hatchery. This has a capacity of 36 million PL/yr and was producing 3 million PL/month in mid-1999, partly to stock its own farm and partly to supply another new but smaller farm (2–3 ha). A clearwater, recirculation system is employed for this phase and the tanks are stocked at 80 to 100 larvae/L. Each cycle takes approximately 35 days. The hatchery (and grow-out facilities) are about 1500 km inland. Postlarvae have been sold at US$ 15/1000 and 0.02 to 0.03 g juveniles at US$ 30/1000 for the past 5 years. In September, after metamorphosis, PL are stocked in a plastic-roofed area with 24 rectangular 25 m^3 concrete tanks. Here they remain until day 8 to 10, when they are transferred to nursery ponds or sold. The nursery ponds are stocked at 80/L; this stage lasts about 45 to 60 days (October–November). The 0.5 ha grow-out ponds are rectangular (25 × 200 m) and are stocked in December at 7/m^2 (range 5–10/m^2). Both organic (cow dung) and inorganic (diammonium phosphate) fertilisers are used. The farm-made feed achieves an FCR of 2.2 : 1. The prawns are cull-harvested once and the ponds are drained in May or June, depending on the water temperature. Prawns are all sold domestically, being destined for retail markets in Buenos Aires, using the farm's own trade mark. During the 5 months 'down-time' the ponds are kept dry and are not chemically treated. They are tilled 2 to 3 weeks before re-filling. No grow-out diseases have been experienced in 10 years of operation. The major problem is the length of the 'down-time'. Occasionally, in the summer when biomass is high, oxygen depletion sometimes occurs before a storm. No information about the second farm (near Formosa) was available except that it stocked 250 000 PL in 1998.

Interest in *Macrobrachium* culture was strong in **Colombia** in the 1970s and 1980s, originally in local species (*M. acanthurus* and *M. carcinus*) but later in the introduced species, *M. rosenbergii*. In 1992 it was reported that there were two projects, a number of small farms, and four hatcheries producing *M. rosenbergii* PL. Annual production expanded to a peak of 60 t in 1990 but declined to 10 t by 1993 and 1994 because many farmers converted to red tilapia farming. From 1995 onwards no FAO production data have been available. According to information gathered during the preparation of this chapter, there was no commercial farming in 1999 and none is anticipated in the near future. For now, Colombian freshwater prawn farming appears to have been entirely vanquished by tilapia farming.

The status of freshwater prawn farming in **Ecuador** is confused. Some observers reported that no commercial success had occurred by 1992, while others cited about 400 ha of ponds in production by 1989. The FAO has consistently reported that Ecuador produces more freshwater prawns than any other country in the western hemisphere, averaging over 820 t/yr in the decade 1989–1998. However, the informal survey conducted during the production of this book failed to elicit any information on this sub-sector of the Ecuadorian aquaculture industry, which is dominated by marine shrimp farming.

The problems experienced by freshwater prawn farmers in **French Guiana** have been described in Chapter 19. FAO statistics show a production between 83 and 89 t/yr in 1989–1991, but none from 1992–1996. Activities have now re-started and the FAO reported a production of 7 t in 1997 and 18 t in 1998. Farms have appeared again in the Cayenne area since 1995 and there is (in 1999) one between 2.0 and 4.9 ha and another which is larger than 5 ha. The other two are between 0.4 and 1.0 ha. Production is integrated with livestock and crop production. Annual production is not expected to expand beyond about 20 t/yr because of limited market opportunities, due to high production costs and competition from Asian suppliers of frozen prawns. One farm sells its products either in frozen form in metropolitan France, or chilled in the French Antilles. It also sells some prawns to prawn farms in Martinique and Guadeloupe, which use them to supplement their own production. Postlarvae are obtained partly from a single local hatchery and partly from Martinique. Prices for PL are 50% less than in the late 1980s. Ponds are 0.5 ha and rectangular. The commercial feed costs about US$ 920/t. Ponds are normally operated for 2 years, followed by draining, and drying and liming for 1 month. Water quality poses a problem during the dry season and predation in grow-out ponds by birds, snakes, and caimans occurs. Selective cull-harvesting is used, until the ponds are finally drained. Some of the harvested prawns are sold at the farm gate (5%), while about 15% goes to restaurants and local retail markets. About 40% are sold to wholesalers. In total, about 80% of the national output is not consumed domestically, being exported to France (including Martinique and Guadeloupe) and Belgium.

Trials of freshwater prawn farming (*Macrobrachium* spp.) occurred in **Paraguay** in 1991 but were suspended due to lack of financing. Despite the apparently anomalous production data reported by the FAO for **Peru** for 1994 (212 t) and 1995 (100 t), declining to 23 t for 1997 and 45 t in 1998, actual farmed freshwater prawn production is estimated to have shown a gradual decline from a high of 26 t in 1993 to 16 t in 1998. The estimate for the first half of 1999 was 7 t. The main area of cultivation is in the northeast of the country. Production is not expected to decline further; indeed, if the trials of a new production model by one group are successful, output may expand. Fourteen farms existed in 1999. Only two were larger than 5 ha, while there were four from 0.4 and 0.9 ha, and eight between 1.0 to 4.9 ha. Three hatcheries, all owned by grow-out farms and all inland, were reported in 1999. Their average output was 2 to 3 million PL/yr. Broodstock are obtained from grow-out facilities and the hatcheries operate clearwater, recirculation systems stocked at 60 to 90 larvae/L. The prices for PL have been markedly reduced over the past 10 years from US$ 50/1000 to US$ 14/1000 in 1999. Nursery ponds are generally stocked at 150 PL/m^2, while grow-out ponds are stocked with juveniles at 5 to 7/m^2. Grow-out ponds are typically 0.2 to 0.45 ha and rectangular. Some farms make their own pelleted feeds while others buy a Peruvian marine shrimp feed costing US$ 640/t, which achieves an FCR of 1.7:1. Some farms combine bought-in with farm-made feeds. Fertilisers are not commonly used. The problems experienced are common to all farms: oxygen depletion and seasonal shortages of water. Most farms practise batch harvesting but one is reported to operate a continuous culling system. The mean 'down-time' between crops is 2 weeks. The harvested prawns are partly sold at the farm gate and partly to retail markets in other parts of the country. None is exported.

Early interest in freshwater prawn farming was expressed in **Suriname** but production remained below 1 t/yr in the decade 1989–1998. Pilot-scale culture occurred in **Uruguay** in 1984 and again in 1989 but no commercial production has been reported to date.

The FAO reported a production of 2 t in 1989 in **Venezuela**. The sole farm at that time supplied a few restaurants but found the species difficult to market. In 1991, three companies were said to be producing *M. rosenbergii*, one of which produced 20 t in 1990. However, freshwater prawn farming in Venezuela appears to have had a chequered history. The destruction of several introduced broodstock of *M. rosenbergii* because of import violations in 1991 provoked an immediate flight of investors. FAO statistics indicate that farmed production of freshwater prawns in Venezuela varied between 22 and 31 t/yr in every year between 1990 and 1998, with the exception of 1994 (13 t). Despite this, in 1999 one correspondent stated that there is currently no farming of *M. rosenbergii* in the country. However, one company which had abandoned production after 1989 reported a revival in interest and is now rearing a 50 000 batch to try out a new marketing approach. It hopes that farming will take off again in the early 2000s due to the application of processing technology and improved marketing programmes.

17.3 Central America and the Caribbean

17.3.1 Central America

In 1999 there was only one commercial-scale freshwater prawn farm in **Costa Rica**, in the northwest province of Guanacaste near Playas del Coco. This farm sells PL to another farm, some 28 miles (45 km) distant, which is operated by the national university, as well as to a number of 'hobby farms'. Previously there was also a small farm operated by the banana co-operative. Total farmed freshwater prawn production in Costa Rica was reported to be nearly 80 t/yr in 1996 and 1997 but the production in 1998 is clouded with some uncertainty (see footnote[b] to Table 1.2 in Chapter 1). Production in the existing commercial farm, which was 13 t and 17 t in 1993 and 1994, respectively, rose to 20 t in each of 1995 and 1996. In 1997, 19 t were produced and the farm achieved a high of 23 t in 1998. Some 20 t were produced by the farm in the first 8 months of 1999. Local correspondents indicate that the FAO data for 1996–1998 appear to be a considerable overestimate.

Despite relatively steady output over the past 5 years, the sole commercial-scale farm predicts that production will decrease unless new techniques (a number, including the possibility of all-male culture, are being investigated) make production economically profitable. The farm operates its own hatchery, some 16 km from the Pacific Ocean, which has a capacity of 12 million PL/yr, obtains its broodstock from its grow-out facilities and stocks larvae at 80/L in a clearwater recirculation system. Postlarvae are available at US$ 20/1000, about the same as 10 years ago. Grow-out ponds are 1 ha (250 × 40 m) and are dried after 2 years, or more frequently as needed. About 50% of the feed used is farm-made; the FCR of the available commercial aquafeed is about 6:1. Urea is used to promote an algal bloom. Some prawns have been produced in polyculture (1–2 t in some years) with tilapia and the farm is contemplating polyculture with catfish in the future. The only major problem reported was the high cost of water, which is not always available from the farm's own deep wells. Ponds are harvested on a continuous culling management system and the prawns are all sold domestically, mainly at the farm gate (33%) and to a distributor (50%). The rest are sold to local restaurants. The market is strong; further details about the marketing strategies employed by this farm are contained in Chapter 19.

Macrobrachium rosenbergii has been farmed in **El Salvador** since about 1988. Farms in 1992 were reported to be small (none larger than 5 ha), purchasing their PL from Puerto Rico, Guadeloupe or Costa Rica. Up to 600 ha of suitable land was said to be available for freshwater prawn farming. FAO data show that national production rose gradually from 1 t in 1989 to 14 t in 1997. Production in 1998 was reported to be 12 t.

According to the FAO, farmed *M. rosenbergii* production in **Guatemala** ranged from 4 to 12 t/yr in the years 1986–1991. Between 1992 and 1998 production ranged from a low of 5 t in 1996 to a high of 99 t in 1995. The most recent figure available is 52 t in 1998. The FAO also reports that small quantities (2–10 t/yr between 1994 and 1998) of 'freshwater prawns and shrimps not elsewhere included (Palaemonidae)', presumably mainly *M. americanum* and *M. carcinus*, are also being farmed.

Minimal prawn farming activity has been reported to the FAO by **Honduras** during the decade 1989–1998. The reported harvest of farmed freshwater prawns in **Panama** fell from 16 t in 1986 to 5 t in 1989. From 1990–1997 production averaged just under 4 t/yr; the level reported to the FAO for 1998 was less than 1 t.

17.3.2 Caribbean

While **Cuba** does not report the production of *M. rosenbergii* specifically, it does report a significant output of farmed 'freshwater prawns and shrimps not elsewhere included (Palaemonidae)' to the FAO. This may include *M. rosenbergii*, as well as other *Macrobrachium* spp. National production averaged 1130 t/yr between 1989 and 1996, and was about 2000 t in 1997 and 1998. During the production of this book, several attempts were made to clarify this situation but, unfortunately, without success.

A feasibility study on prawn farming in the small mountainous island of **Dominica** was conducted in 1977. Freshwater supplies are abundant and potential was evident but limited by the few areas of valley land, and from competition for resources from agriculture. Despite this, *M. rosenbergii* was introduced in 1984, a small hatchery opened in 1986, and production has continued. The FAO shows an average annual production of about 2.4 t/yr in the years 1992–1998.

Up to 1991 at least, shrimp farmers in the **Dominican Republic** concentrated on freshwater prawns. By 1990, there were 35 freshwater prawn farms and it became the leading producer of *M. rosenbergii* in Latin America. According to the FAO, production rose to a peak of 961 t in 1994 but declined to about a tenth of that during the years 1995–1998. Currently, the main production areas are Bayagunna, Monte Plata (northeast of Santo Domingo), Baní (west of Santo Domingo) and Cabrera and Copellito (in the northeast of the country). Some farms are 2 to 5 ha but most are larger. Two farms (5.5 ha and 12 ha) have been producing continuously since before 1995; others ceased operations, mostly for financial reasons, about 2 years after commencement. Two large farms (15 ha and 50 ha) were reported to be switching production from freshwater prawns to tilapia farming in 1999. In 1999 there were three inland hatcheries, mostly owned by grow-out farms and typically producing 4 million PL/yr. Stocking rates are 50 to 100/L and hatcheries exchange 100% of water/day in a clearwater system. Broodstock are obtained from grow-out ponds and PL are sold at

US$ 12.5/1000. Grow-out ponds are stocked initially at 80/m^2 for 2 months and then at 6.5/m^2 for 4.5 months. Most ponds are 0.2 to 0.7 ha and rectangular in shape. A few farms operate a continuous system but most operate a batch culture system, with a 2-week down-time between cycles. Some culling takes place before the final drain harvest. Locally manufactured feed (US$ 225/t) achieves an FCR of 2.5–3 : 1. Poultry manure and inorganic fertilisers are used in moderation. The major problem reported is water availability, because of high pumping costs. Most of the harvested prawns go to restaurants and hotels and a little to wholesalers. There is no export trade in this commodity.

The farming of freshwater prawns in **Guadeloupe** has similarities to that in Martinique (see below). FAO statistics show that national production, 40 t or more per year from 1984–1993, declined to 26 t in 1994 and 30 t in each of 1995 and 1996. A further decline to 20 t in 1997 and 14 t in 1998 has occurred. Recent estimates are that production was expected to remain at about this level in 1999. In 1999 there were 11 farms, two of them on 'standby'. All operational farms had a surface area of less than 5 ha. In 1977, when prawn farming commenced, there were expectations that national production might reach 200 t/yr by the late 1980s. This never materialised because of lack of experience in aquaculture, extremely high investment costs, and competition for resources with sugar cane or banana production and with tourism. High selling prices (>US$ 18/kg) are required to make farming profitable. Frozen prawn imports from Thailand, 30 t in 1992, have stabilised since 1997 at around 200 t/yr; the supermarket price is US$ 8 to 10/kg. It is forecast that local production may return to about 40 t/yr, through marketing strategies which emphasise first-class fresh or live prawns and good hygienic practices, together with an appeal to 'eat local products'. The only hatchery has a capacity of 20 million PL/yr, stocks 90 larvae/L in a clearwater closed recirculation system on a coastal site, and obtains its broodstock from grow-out ponds in various farms. Postlarvae are sold for US$ 25 to 30/1000, down from US$ 30 to 35/1000 in 1989. Hatchery virus problems have been experienced in summer months during the 5 years up to 1999. All grow-out occurs in monoculture ponds, typically rectangular and 0.15 ha, which are usually stocked at 12 PL/m^2/yr in those that operate a continuous rearing system. Very few farms include nursery rearing. Fertilisation, usually with poultry manure, is sometimes used; local (US$ 650/t) and imported (US$ 1000) commercial feeds are fed. Feed conversion ratios of 5–8 : 1 and 3.5–6 : 1 are achieved for the local and imported feeds, respectively. Prawn farming is normally a secondary activity to banana or vegetable production, and tourism, and management is not always technologically advanced. Water availability during the dry season is also sometimes a problem. Selective harvesting occurs every 2 to 3 weeks, starting 8 months after stocking. Those ponds which are not operated continuously have a final drain-down some 15 to 16 months after stocking. At least 50% of the harvest is sold at the farm gate, while most of the rest goes to hotels and restaurants, with a small amount sold in supermarkets. None is exported, for similar reasons to Martinique.

FAO statistics show national production of farmed freshwater prawns in **Jamaica** expanding to 60 t/yr in 1995, 1996, and 1997 and 65 t in 1998, twice the annual level reported in the years 1988–1992, but local figures from the one existing farm are much lower. Production estimates of 3 t in 1994, rising to 9 t in 1997 and 17 t in 1998, and 11 t in the first half of 1999 were provided. The discrepancy may be because capture fisheries production of other *Macrobrachium* spp. may have been included in the official returns. Only one business is in operation, which rears prawns in polyculture with tilapia on two sites, both more than 5 ha in size. This company estimates that production, supplying a limited local demand, will peak at 50 t/yr before margins will be reduced. There is one inland hatchery, which is owned by the same business, with a capacity of 900 000 PL/month and a 1999 production level of 500 000 PL/month. The internal PL cost is US$ 15/1000. Juveniles (0.01 g) are also produced in hatchery tanks. Broodstock are obtained from the farm's own ponds and larvae are stocked at 56 to 67/L into a clearwater recirculation system. Management of this system has posed problems; an additional difficulty is the limited availability of *Artemia* cysts. Rectangular grow-out ponds of 0.20 to 0.83 ha are stocked at 1.2 to 3.6/m^2 in polyculture with tilapia, which is the primary crop; the company was expected to produce 3200 t of tilapia in 1999. Prawn survival is said to be low but the emphasis has previously been on tilapia. The fish are given a sinking feed made in the company's large feedmill (it is primarily a broiler producer) and an imported floating feed is also provided; no special feeds are given to the prawns, which are therefore regarded as a highly profitable 'bonus' crop. There is no fertilisation. The only reported grow-out problem has been anoxia. The prawns are harvested at the end of the cycle, followed by a down-time of 14 days during which the ponds are sun-dried with occasional liming. Some 80% of the harvest is sold to small-scale wholesalers who use pick-up trucks or motorcycles. The rest goes to retailers who sell it to hotels and restaurants. None is exported.

In 1999 there were a total of 26 farms in **Martinique** (Fig. 17.3). Seven were smaller than 1 ha, two between 1 and 2 ha, and one between 2 and 5 ha, while the largest farm was 10.5 ha. All farms operate monoculture systems in freshwater. Farms are located all over the island, but mainly in the north. National production has declined, from 57 t in 1989 to 38 t in 1992, and remained at 36 to 44 t in the years 1993–1997. The decline to 25 t in 1998 is attributed to an unsuitable management system (continuous culling), the failure of a professional organisation, and virus problems in the hatcheries. However, it is estimated that 26 t had been produced in the first 7 months of 1999 and it is hoped that a new production system ('batch', or 'continuous-batch'), together with a new producers' association, will soon enable the farmers to achieve a total of 50 t/yr again. The difficulties to be faced in achieving that goal include limited land availability (competition with agriculture, industry, and tourism). High production costs prevent the development of an export market; the domestic market is limited (380 000 population and 500 000 tourists/yr).

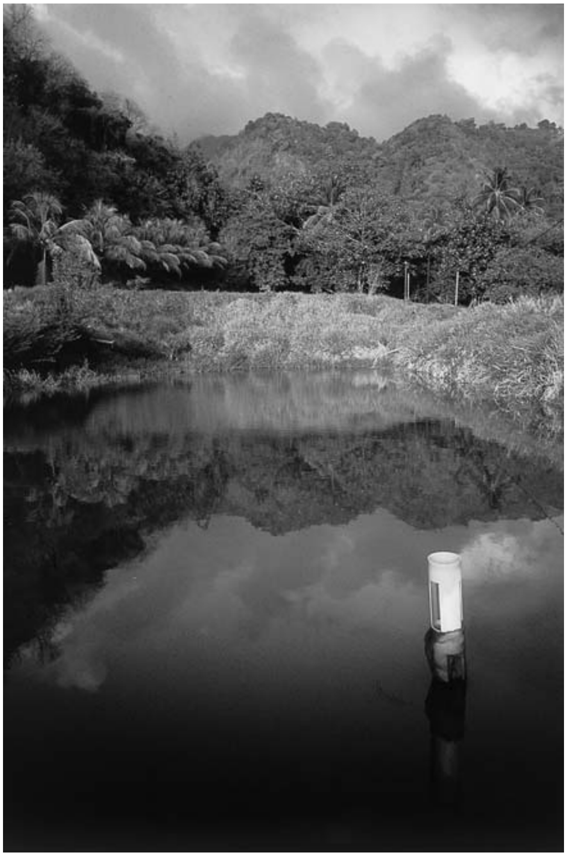

Fig. 17.3 Family-scale freshwater prawn (*Macrobrachium rosenbergii*) farm in Martinique. (Source: Denis Lacroix.)

Farmers in Martinique obtain their PL from two hatcheries, one in Martinique and one in the neighbouring French Overseas Department of Guadeloupe. The local hatchery obtains its broodstock from its own ponds and from commercial farms, and has a capacity of 4 million PL/yr (actual production about 3 million PL/yr). The hatchery is 3.5 km inland and stocks larvae at 80 to 100/L into a clearwater recirculation system. Only one farm uses a nursery system, stocking PL at 45 to 50/m^2 and then stocking juveniles at 9/m^2 into grow-out ponds managed under a batch harvesting system. This farm drains each pond every 8 months, keeping it dry for 1 to 2 weeks between cycles. The pond is washed to remove mud, limed with calcium carbonate (2 t/ha) and fertilised with dry chicken manure (0.2 t/ha). During re-filling with water, an inoculum of greenwater is provided from another grow-out pond. All other farms operate a continuous system, initially stocking PL into their grow-out ponds at 12 to 15/m^2 and selectively harvesting them, with a drain-down every 5 to 10 years.

Grow-out farms in Martinique pay US$ 20/1000 for their PL, down from US$ 50/1000 in the mid-1990s. Ponds vary in size, according to the local topography, but average about 0.1 ha. No farm-made feeds are used. The available commercial feed costs US$ 560/t and achieves an FCR of

4–6:1. On average, farms sell 50% of their output to restaurants and hotels (at US$ 19–20/kg), 40% at the farm gate (US$ 20–22/kg), and 10% to wholesalers (US$ 19–20/kg). The market, for the reasons mentioned above, is totally domestic. A major marketing factor over the 3 to 4 years up to 1999 was the large increase in the import of frozen freshwater prawns (100–150 t/yr) from Thailand and Vietnam at lower prices (US$ 12–16/kg) than locally produced farmed prawns. Farmers now have to develop special marketing strategies to emphasise the quality of their product. Up till now (1999), the main market has been for animals which weigh more than 40 g each. A number of technical problems have also been identified in Martinique. These include a hatchery virus problem (with unknown effects on grow-out performance), the accumulation of mud because of the use of continuous management systems, the transfer of pesticides from adjacent banana plantations, and the lack of a professional society and technical support. As mentioned earlier, the industry is fairly confident that it can solve these problems and increase national production to its earlier peak.

FAO data show production of freshwater prawns in **Puerto Rico** rising to a peak of 439 t in 1992, followed by a rapid decline, due to the closure of the major farm there (see Chapter 8). For each of the 4 years 1995–1998, the FAO reported production as only 45 t/yr. After the large-scale farm ceased to be a commercial prawn farm, the only source of PL for the other farms has been the inland hatchery operated by the University of Puerto Rico, which has a capacity of 2 to 3 million PL/yr. Broodstock are obtained from their own grow-out ponds and a clearwater recirculation system is used. In 1999, Puerto Rican farms were paying US$ 40/1000 for PL, the same as 10 years ago. Sixty-day juveniles (1.5–1.8 g) range from US$ 80 to 140/1000. Recently (1999) PL have also been purchased from a hatchery in Texas. Following this development, it is expected that prawn farming will expand a little; many people are reported to be interested in prawn culture. In 1999, 99% of the grow-out farms were less than 0.4 ha and only 1% were in the range 1 to 2 ha. Rectangular ponds, typically 500 to 700 m^2, are stocked with 5 to 7 juveniles/m^2. Some information on the nursery systems utilised by the defunct major farm is supplied in Chapter 8. Commercial feed is currently used in existing farms and costs US$ 540/t (1999), achieving an FCR of about 3:1. This feed was reported to cause water quality problems, due to poor water stability. Most Puerto Rican farms now practise batch culture, rather than continuous culture and sell their prawns at the farm gate; since the demise of the major farm none has been 'exported' to mainland USA.

In 1989, a state sugar company was reported to have plans to build nearly 200 ha of *M. rosenbergii* ponds in **Trinidad & Tobago**. However, actual construction of only 9.5 ha of ponds and a 0.4 million PL/yr hatchery occurred in 1991. Plans were to sell the production locally at first and to seek a future export market. Several other projects were being considered in the early 1990s but no substantial expansion of national production materialised. A production of 7 t/yr was reported to the FAO for every year between 1994 and 1998. However, contrary to the figures reported to the FAO, production in Trinidad & Tobago is reported to have peaked at 7 t in 1991 but steadily declined thereafter (to 3 t in 1993 and to 0.2 t by 1998). In 1999, during the preparation of this book, it was reported that the sole commercial farm had ceased production and diversified into tilapia farming. The only remaining prawn farm had already become a government research station. Despite this, it was forecast that production will increase again, due to a buoyant local market. Each of two original grow-out farms has (or had) its own inland hatchery. Originally the broodstock came from Jamaica and Texas. The capacity of each hatchery is about 2 million PL/yr and a clearwater (both flow-through and recirculation) system, typically stocked at 20/L, is operated. The grow-out ponds of the original commercial-scale farm (rectangular or square, 0.5 to 1.0 ha) were stocked at 5/m^2, fed commercial feeds (US$ 400/t; FCR 3:1) and batch harvested. Diammonium phosphate was used for fertilisation and ponds were treated with slaked lime between cycles. The major problems are reported to have been water availability and human predation. Most of the harvest from the small (0.01 ha) research farm ponds are sold to employees. This research station also sells a few PL to other farmers but no information on the results is available.

Research and development activities have been reported in a number of **other Caribbean nations**, including Grenada, Haiti, St Kitts, and St Vincent, with minimal production being reported to the

FAO in St Lucia since 1989 and in Grenada since 1995.

17.4 North America

Thermal aquaculture research with *M. rosenbergii* was reported in Canada but all commercial production has occurred in Mexico, Hawaii, and in the southern states of continental USA.

17.4.1 Mexico

According to FAO statistics, the production of freshwater prawns in Mexico declined in the 1990s. Peaking at 410 t in 1988, it fell to 139 t in 1991, rose again to 175 t in 1993 and fell to 90 t in 1996. The FAO figure for 1997 was 112 t and only 37 t was reported for 1998. Local information, based on national statistics, placed production at 112 t in 1996 and 130 t in 1997, the main areas of production being Guerrero, Morelos, Jalisco and Puebla. All production is in freshwater. Estimates of the number of farms in 1999 varied from 11 to 28, most of which are said to be more than 2 ha in area. However, it is also thought that there are a large number of small prawn farms scattered throughout the country which, as in many other countries, makes estimates of national production difficult. In addition, the annual variation in reported national production, which is expected to continue, is caused by differences in the level of technology applied in different regions and to problems due to water quantity and quality. Most farms compete with agriculture for surface water in areas of intensive farming. In central and northern regions, where the farming of *M. rosenbergii* is interrupted in winter, productivity ranges from 0.7 to 1.5 t/ha/yr. In the south and southwest regions 1.0 to 2.5 t/ha/yr is obtained. The initial enthusiasm was for monoculture but polyculture with microphagous tilapia is now favoured in Mexico. Currently (1999) it is estimated that national production is 60 to 70% from polyculture, a complete reversal of the proportion in 1993.

According to local information, there is only one freshwater prawn hatchery in Mexico, on the coast of the State of Guerrero. This public hatchery has a capacity of 11 million PL/yr but its actual production is well below that level. Broodstock are obtained from commercial farms and the hatchery is based on a flow-through greenwater system. The larval stocking rate is 60/L. Ten years ago (1989), PL cost US$ 3/1000, which rose to US$ 8/1000. Currently (1999) PL are available free from the government hatchery, presumably in an attempt to stimulate the sector.

All grow-out takes place in ponds, which are typically 0.07 to 0.20 ha and rectangular. About 20% of the farms use farm-made feeds; half of these also utilise the commercial feeds (US$ 570–780/t; FCR 2.0–2.5 : 1) which the remaining 80% of farms use. Chicken and cattle manure, as well as triple superphosphate are used for fertilisation. About 50% of production is sold at the farm gate, while 40% goes to restaurants and hotels and 10% to local retail markets. None is exported. It is interesting to note that the production of farmed *M. rosenbergii* in Mexico is dwarfed by the output of indigenous species of *Macrobrachium* from the capture fisheries sector (see Chapter 22). It is also reported that *M. americanum* achieves a much higher market value than *M. rosenbergii*.

17.4.2 USA

The pioneering studies in Hawaii not only had a profound influence on global developments in freshwater prawn farming (see Chapter 1) but also founded commercial farming in that State. This, followed by the considerable US research work that has continued ever since, also stimulated prawn farming in other States. National farmed production appears to have remained above 140 t/yr since 1989, with a peak of 184 t in each of the years 1990 and 1991. However, no FAO data are available for recent years. The last official figure was 159 t for the year 1994.

Apart from Hawaii, which has an almost ideal temperature range, most efforts to produce *M. rosenbergii* in the USA have been in temperate zones, including Kentucky and South Carolina. A gradual increase in national production is expected. Some Mississippi catfish farmers are reported to be trying prawn culture on a pilot scale. If these trials are successful, production could rise quite dramatically. Pilot-scale culture of freshwater prawns has been reported in Arizona and California. Through 1995–1999, only 400 kg/yr was produced from two ponds totalling 0.61 ha in South Carolina, using PL purchased from a hatchery in Texas. The

PL are nursed and stocked into the grow-out ponds at 5.4/m^2. The production is sold at the farm gate, or to special order.

The current means that are used to address the problems of seasonal culture are discussed fully in Chapter 11. It is estimated that production in Kentucky will be about 7 t in 1999, twice as much as in 1998. Most farms in Kentucky are less than 0.5 ha but larger farms are expected to emerge. Most PL come from one inland commercial hatchery in Texas, which has a capacity of about 3 million PL/yr, but supplies are also available from some academic facilities. The commercial hatchery operates a clearwater recirculating system, obtaining its broodstock from grow-out ponds and stocking larvae at 25 to 80/L. Some regional nurseries exist (one in-State in Kentucky), but most farms operate their own, stocking them at about 5 PL/m^2 of substrate. In 1999, PL were available at US$ 10 to 30/1000 and 60-day juveniles at US$ 50 to 100/1000. Prices have remained stable over the 1990s. In Kentucky, where prawn farming is practised as part of a diversified farming operation, grow-out ponds are typically rectangular and range from 0.2 to 0.4 ha. Commercial feeds are used, with an FCR of 2.5 : 1. Distillery by-products are used as an organic fertiliser for the first 2 months, followed by pelleted feed. Production averages 1.2 t/ha/crop (year) but experimental work is improving this to 1.7 to 1.8 t/ha through the use of substrates. Water availability and high pH in newly constructed ponds have been the major problems in this State. Ponds in Kentucky are completely harvested by September–October. A few remain dry until the following year but most are refilled and a winter crop of trout may be raised. Some 70% of the prawns are sold at the farm gate (at US$ 13–22/kg), while 20% go to restaurants and 5% are sold in local retail markets. About 5% is exported to Asian markets in Canada and there is good potential for expanding this trade if holding and transportation facilities are improved. One freshwater prawn farm in Mississippi, established in 1997, is producing over 27 t/yr (1999).

In 1999 there were eight freshwater prawn farms in Hawaii, mainly small, family-operated businesses. Kahuku and Kaneohe on the island of Oahu (five farms) are the major production areas. Only two farms are larger than 5 ha. All operate monoculture systems in freshwater. Total production area (1999) is estimated to be about 40 ha and annual State production in the years 1993–1998 ranged from a high of 40 t in 1993 to a low of 7 t in 1996. 1998 production was estimated to be nearly 14 t. There are only two artisanal hatcheries now, operated by grow-out farms; these have a limited capacity. Surplus PL are sold to other farms. It is interesting to note that these hatcheries still operate the greenwater system introduced by Takuji Fujimura and his team (see Chapter 1). Some are inland, using trucked seawater from wells or, occasionally, artificial seawater. Broodstock is obtained from their own ponds, or those belonging to the farm desiring PL. Locally produced PL are currently (1999) US$ 35 to 50/1000, significantly higher than 10 years previously, when they fluctuated from US$ 15 to 25/1000. There seems to be a resurgence of interest in freshwater prawn farming in Hawaii, due to high market prices for *Macrobrachium*. One farm purchases PL from California. Rectangular, 0.2 to 0.6 ha, grow-out ponds are reported to be stocked at a rather high density (25 PL/m^2); no juveniles are stocked.

Fertilisers are added to promote the growth of phytoplankton. Feeds are shipped in from continental USA and cost (1999) US$ 1100 to 1650/t. Noting the high costs of feed and PL, it is no wonder that the major constraining factor to freshwater prawn farming in Hawaii is reported to be operational costs. However, this is partially offset by the extremely high value of the harvested product (Tables 17.2 and 17.3). Harvesting is mainly by continuous culling, with the ponds only occasionally being drained, prior to a 2-week drying and liming process, during which the bottom sediment is removed. Prawns are sold live to ethnic seafood restaurants (55%) and retail markets (45%) centred around Chinatown in Honolulu, since processors deem the supply to be too small and irregular to be of interest. All farm production is consumed within Hawaii.

17.5 Africa

Freshwater prawn farming to date (1999) has been extremely limited in Africa, despite technical potential. Production in Mauritius is described in section 17.5.1 and activities in other countries grouped within section 17.5.2.

Table 17.2 Examples of farm-gate values for freshwater prawns (*Macrobrachium rosenbergii*) in 1999.

Location and date (month/year)	Price (US$/kg)	Type and size (where stated)	Notes
Bangladesh ?/99	7.1	Not stated	National average
Bangladesh 10/99	9.2	Live, 5/kg	
	13.2	Head-off, fresh, 5/kg	
Brazil (South) 9/99	7.0–10.0	Head-on, frozen, 33–50/kg	
	20–40% above frozen prices	Head-on, fresh, 33–50/kg	Seasonally available
Brazil (Espírito Santo State; main production area) mean/99	3.5–4.0	Head-on fresh on ice, 15–20 g	
	4.0–5.5	Head-on fresh on ice, 20–30 g	
	5.5–6.5	Head-on fresh on ice, 30–40 g	
	6.5–7.5	Head-on fresh on ice, >40 g	Some farms reported to have sold 40-g size directly to consumers at US$ 10.0–12.0/kg in 5/99
Brazil (Northeast) 9/99	2.7	Head-on, fresh, 12 g	Individual purchasers
	3.3	Head-on, soft-shell	Individual purchasers
	4.1–5.5	Head-on, fresh, 20–30 g	Individual purchasers
	5.5	Head-on, fresh, 35–40 g	Individual purchasers
	9.8	Head-on, >60 g	Few available, for restaurants
China (East Central) 9/99	3.6–4.4	Live	
French Guiana 9/99	15.5	Frozen, 10–20/kg	Individual purchasers
	13.0–14.0	Frozen, 10–20/kg	Restaurants and supermarkets
	14.0	Frozen, 20–30/kg	Individual purchasers
	12.0–13.0	Frozen, 20–30/kg	Restaurants and supermarkets
French Polynesia 12/99	24.0	Head-on, 30–40/kg	
	25.0	Head-on, 20–30/kg	
Guadeloupe 9/99	25.0	Head-on, fresh or live	Individual purchasers
	22.0	Head-on, fresh or live	Restaurants
	20.0	Head-on, fresh or live	Supermarkets
	22.5–23.75	Head-on, frozen	Individual purchasers
	20.0–20.9	Head-on, frozen	Restaurants
	18.0–19.0	Head-on, frozen	Supermarkets
Guam 9/98	15.4	Head-on, fresh or frozen, 55/kg	Sold by farmers at farm gate or at weekend flea markets
India 10/99	5.8	Head-on, fresh on ice, 50–80 g	Collectors (for export) price
	5.8–8.1	Head-on, fresh on ice, 80–125 g	Collectors (for export) price
India 1/00	3.5–4.7	Head-on, live or dead, fresh, no ice, very large (~300 g)	On-site prices paid for first prawns harvested from newly stocked reservoirs by inexperienced fishermen
Jamaica 9/99	8.8	Live, size not stated	Washed; berried females have had eggs removed
	13.8	Head-on, frozen, pouch packed, 25–35/kg	
	11.6	Head-on, frozen, pouch packed, 35–45/kg	
	10.4	Head-on, frozen, pouch packed, 45–55/kg	

(Continued on p. 314.)

Table 17.2 *Continued.*

Location and date (month/year)	Price (US$/kg)	Type and size (where stated)	Notes
	8.3	Head-on, frozen, pouch packed, >45/kg	
	16.2	Head-on, frozen, pouch packed, 'jumbo' (size not stated)	
	16.3	Head-off, frozen, pouch packed, size not stated	
Malaysia 9/99	7.0–9.0	Live	
Martinique 9/99	19.0–30.0	Head-on, live, 5–50/kg	Individual purchasers
	28.0	Head-on, frozen, 5–10/kg	Supermarkets
	17.5–20.5	Head-on, live, 20–50/kg	Restaurants
	19.5	Head-on, live, 20–30/kg	Supermarkets
	21.0	Head-on, frozen, 20–30/kg	Individual purchasers
	20.0	Head-on, frozen, 20–30/kg	Restaurants
	18.0	Head-on, frozen, 30–50/kg	Individual purchasers
	17.0	Head-on, frozen, 30–50/kg	Restaurants
	17.0	Head-on, frozen, soft shelled	Individual purchasers
	15.0	Head-on, frozen, soft shelled	Restaurants
	19.0	Head-on, fresh, soft shelled	Individual purchasers
	16.0	Head-on, fresh, soft shelled	Restaurants
Mauritius 9/99	8.2	Head-on, chilled, >99/kg	Individuals or restaurants
	12.0	Head-on, chilled, 33–39/kg	Individual purchasers
	10.8	Head-on, chilled, 33–39/kg	Restaurants
	14.1	Head-on, chilled, 20–32/kg	Individual purchasers
	12.8	Head-on, chilled, 20–32/kg	Restaurants
	15.9	Head-on, chilled, 11–19/kg	Individual purchasers
	14.7	Head-on, chilled, 11–19/kg	Restaurants
	16.5	Head-on, chilled, <11/kg	Individual purchasers
	15.7	Head-on, chilled, <11/kg	Restaurants
	12.6	Head-on, frozen, packed[a] 33–99/kg	Individual purchasers
	11.4	Head-on, frozen, packed[a] 33–99/kg	Restaurants
	14.9	Head-on, frozen, packed[a] 20–32/kg	Individual purchasers
	13.7	Head-on, frozen, packed[a] 20–32/kg	Restaurants
Thailand 9/98	4.6–6.1	Whole, <30/kg	
	2.7	Whole, >30/kg	
Thailand (Central provinces) 9/99	3.6	Head-on, chilled, size not stated	
Thailand (Supanburi) 9/99	4.5	Live, 15/kg	
	3.8	Live, 15–20/kg	
	3.0	Live, 20–35/kg	
	2.1	Live, 40–50/kg	
	3.8	Head-on, chilled, 15/kg	
	3.0	Head-on, chilled, 15–20/kg	
	2.8	Head-on, chilled, 20–35/kg	
	1.9	Head-on, chilled, 40–50/kg	
Thailand 11/99	3.1	Live, 20/kg, males	
	3.9	Live, 17/kg, males	
	4.7	Live, 15/kg, males	

Table 17.2 *Continued.*

Location and date (month/year)	Price (US$/kg)	Type and size (where stated)	Notes
	1.3–1.6	Live, 17–20/kg, males	Terminal males
	1.8–2.1	Live, 70–80/kg, females	
	2.3–2.6	Live, 30–40/kg, females	
USA (Kentucky) 9/99	13.2–22.0	Live, mixed sizes	
USA (Mississippi) ?/99	5.5–6.1	Head-on, 10/kg	
USA (Hawaii) 10/99	22.0	Size and form not stated	
Vietnam 10/99	8.6	Live, 100 g or more	Price paid at collection sites for farmed and captured prawns
	5.9	Live, 50–100 g	Price paid at collection sites for farmed and captured prawns
	3.6	Live, <50 g	Price paid at collection sites for farmed and captured prawns

[a] 300 g plastic punnets.

17.5.1 Mauritius

Following the pioneer work of the late Rogene Thompson and her co-workers, production of farmed prawns reported by Mauritius to the FAO averaged 50 t/yr (range 42–63 t) from 1989–1997. However, production fell to only 28 t in 1998 and local reports were that only 9 t was produced in the first half of 1999. Production has declined since 1996 because of the increasing use of prawn ponds for rearing other species, notably red tilapia and the redclaw crayfish *Cherax quadricarinatus*. Two farms closed down because their water supplies were used for industry and tourism (hotels). In addition, Mauritius has faced a very severe drought and some farms completely ran out of water. It was hoped that the water situation would return to normal during the 1999 winter period (July–September). Most production occurs in the east and southeast coastal areas.

Almost all production is from monoculture but small amounts (0.1–0.4 t/yr) have been produced in polyculture with red tilapia hybrids (*Oreochromis niloticus* × *O. aureus*) since 1996. In 1999 there were a total of 14 grow-out farms. One of these exceeded 5 ha in size, while five were less than 0.4 ha, six were between 0.4 and 1.9 ha and two between 2.0 and 4.9 ha. Annual production was expected to decline during 1999 and 2000 for the reasons mentioned above but, owing to increasing market demand, is expected to expand after that.

Two hatcheries exist but one has been inactive since the early 1990s. The remaining hatchery is operated by a grow-out farm and also supplies PL to other farms, which are within a 1.5-hour drive. No PL are imported. The hatchery has a potential of 50 million PL/yr; up to 1996 it sold about 5 million annually but this fell to 2.5 million/yr after that, for the reasons mentioned above. The hatchery, once expected to be able to export PL to other African countries, has no foreign client so far (1999). The original broodstock came from Hawaii but now the hatchery obtains its supply from grow-out ponds. While some reduced fecundity has been noticed, no degeneration in grow-out performance has been observed. Nevertheless, new stock may be imported in future, to avoid inbreeding. Originally, following its Hawaii origins, the coastal hatchery operated a greenwater system but switched to a clearwater recirculation system in 1993. A three-phase production system is used. In phase 1 (larval stages I–V) the stocking rate is 600 to 900/L. The stocking rate decreases to 220 to 250/L in phase 2 (larval stages V–X) and to 75/L from stage X to

Table 17.3 Examples of retail and wholesale prices for freshwater prawns (*Macrobrachium rosenbergii*) in 1999.

Location and date (month/year)	Price (US$/kg)	Type and size (where stated)	Vendor[a]	Source[b], where known
Australia (Sydney Fish Market) 9/99	9.0–9.6	Fresh, head-on	W	I (Vietnam)
	14.4	Fresh, head-on	R	I (Vietnam)
Bangladesh 10/99	18.2	Head-off, fresh, 5/kg	R	D
	13.1	Live, 5/kg	R	D
	14.6	Head-off, fresh, 15/kg	R	D
	13.1	Head-off, fresh, 20/kg	R	D
	11.1	Head-off, fresh, 30/kg	R	D
Belgium 5/98	16.6	Head-off, frozen, 1 kg packs, 16–20/kg	R	I
	17.5	Head-off, frozen, 0.5 kg packs, 16–20/kg	R	I
	14.8	Head-off, frozen, 0.5 kg packs, 31–40/kg	R	I
	11.5	Head-off, frozen, 0.5 kg packs, 51–60/kg	R	I
Belgium 9/99	9.2	Peeled and cooked, 160–260/kg	R	I
	11.8	Peeled tails, 80–100/kg	R	I
	15.8	Peeled tails, 35–45/kg	R	I
	23.4	Peeled, tails, 20–30/kg	R	I
Belgium (Ghent) 9/99	Av: 15.0 (varies by size)	Frozen, tails, packed in 0.5, 1.0 or 2 kg bags	R	I
	20.0	Peeled, sold fresh on ice (but probably de-frozen)	R	I
Belgium (Ghent) 9/99	23.0	Head-off, 13–17 prawns/200 g packs	R	I
Belgium 9/99	9.2	'Mini-shrimp', peeled and cooked, 160–260/kg	R	I
	11.8	Head-off, peeled, frozen, 80–100/kg	R	I
	15.8	Head-off, peeled, frozen, 35–45/kg	R	I
	22.4	Head-off, peeled, frozen, 20–30/kg	R	I
Brazil (Porto Alegre) 9/99	15.0–18.0	Head-on, frozen, 20–30 g	R	D
Brazil (Espírito Santo State; main production area) range/99	4.6–5.2	Head-on, fresh on ice, 15–20 g	R	D
	5.2–7.2	Head-on, fresh on ice, 20–30 g	R	D
	7.2–8.5	Head-on, fresh on ice, 30–40 g	R	D
	8.5–9.8	Head-on, fresh on ice, >40 g	R	D
Brazil (Northeast) 9/99	3.3	Head-on, fresh, 12 g	R	D
	5.5–6.6	Head-on, fresh, 20–30 g	R	D
	6.6	Head-on, fresh, >40 g	R	D
China (Nanhai, Guangdong) 9/99	4.4	Live, <20/kg	W	D

Table 17.3 *Continued.*

Location and date (month/year)	Price (US$/kg)	Type and size (where stated)	Vendor[a]	Source[b], where known
China (Huangsha, Guangdong) 9/99	2.7	Live, 22–40/kg	W	D
China (Zhongshan, Guangdong) 9/99	2.5	Live, size not stated	W	D
China (Nanjing) 9/99	4.4	Live, size not stated	W	D
China (Hangzhou) 9/99	4.1	Live, >42/kg	W	D
China (Changshu, Jiangsu) 9/99	4.3	Live, size not stated	W	D
China (East Central) 9/99	5.5–7.3	Head-on and graded, but minus claws	R	D
China (Beijing) 1/00	9.7	Live	R (Supermarket)	D
France (Paris) 9/99	11.2	10/kg size, head-on, IQF[c]	R	I
France (Paris) 9/99	12.7	7–8/kg size, head-on, IQF[c], sold in packets of five	R	I
French Guiana 9/99	17.0–18.0	Head-on, frozen	R	D
French Polynesia (Tahiti) 9/99	33.0	Head-on, 20–30/kg	R (Supermarket)	D
Guadeloupe 9/99	28.0	Live	R	D
	9.0–12.0	Head-on, frozen	R	I (Thailand)
India 10/99	2.3–2.5	Head-on, mostly fresh, 100–150 g, mixed sizes	M	D
Japan ?/98	10.0	Not stated	M	Not stated
Malaysia 9/99	11.0–12.0	Live	W[d]	D (and wild-caught)
Martinique 9/99	23.0–26.0	Live or fresh	R	D
	13.0–17.0	Frozen, head-on, 10–20/kg	R	I (Thailand and Vietnam)
Mauritius 9/99	10.6	Head-on, chilled, >99/kg	R	D
	15.7	Head-on, chilled, 33–99/kg	R	D
	16.3	Head-on, chilled, 20–32/kg	R	D
	18.3	Head-on, chilled, 11–19/kg	R	D
	14.5	Head-on, frozen, packed[e], 33–99/kg	R	D
	17.3	Head-on, frozen, packed[e], 20–32/kg	R	D

(Continued on p. 318.)

Table 17.3 *Continued.*

Location and date (month/year)	Price (US$/kg)	Type and size (where stated)	Vendor[a]	Source[b], where known
Philippines 11/99	6.2	Head-on, fresh, 10/kg	R	Capture fisheries
	3.7–5.0	Head-on, fresh, ⩾10/kg	R	Capture fisheries
Singapore 9/99	35.4	Live: approx. 20 cm and 200–250 g each	M	I (Malaysia: probably wild)
Singapore 9/99	14.7	Live: approx. 20 cm and 200–250 g each	M	I (poor quality)
Solomon Islands 9/99	2.0/parcel	20/parcel, wrapped in coconut leaves, 7.5–10.0 cm long	Roadside	D (Wild)
Thailand 9/99	5.0	Head-on, chilled, size not stated	M	D
	7.6	Head-on, chilled, 20–30/kg	R (Supermarket)	D
	5.6	Head-on, chilled, 30–50/kg	R (Supermarket)	D
	5.6	Head-on, chilled, 15–20/kg	R (Local shop)	D
	4.2	Head-on, chilled, 20–30/kg	R (Local shop)	D
	3.6	Head-on, chilled, 30–50/kg	R (Local shop)	D
	2.9	Head-on, chilled, 50–60/kg	R (Local shop)	D
Thailand 10/99	4.7	Live or head-on, chilled, male, >15/kg	M	D
	5.1	Live or head-on, chilled, male, <15/kg	M	D
	2.1–2.3	Head-on, chilled, female, 70–80/kg	M	D
	2.3–2.6	Head-on, chilled, female, 50–60/kg	M	D
	2.5–3.1	Head-on, chilled, female, 30–40/kg	M	D
UK 5/99	31.7	Head-off, raw, chilled (previously frozen), size not stated	R (Supermarket)	I (Thailand)
UK 10/99 and 2/00	25.5	Head-off, raw, chilled (previously frozen), 40 tails/kg, reduced price	R (Supermarket)	I (Thailand)
USA (Kentucky) 9/99	22.0	Head-off, frozen, 40–50 tails/kg	R	I (mainly Bangladesh)
	30.0	Head-off, frozen, 17–18 tails/kg	R	I (mainly Bangladesh)
USA (Washington) 9/99	10.3	Head-on, frozen, 9–13/kg	W	I
USA (Hawaii) 10/99	33.1	Size and form not stated	R	D
	55.1	Size and form not stated	T	D
Vietnam 10/99	8.6–9.4	Live, 100 g or more	M	D
	5.9–6.8	Live, 50–100 g	M	D
	3.6–4.3	Live, <50 g	M	D

[a] W = wholesale; R = retail supermarkets and shops; M = market; T = in restaurants, to the consumer.
[b] I = imported from unknown source; D = domestic.
[c] IQF = individually quick frozen.
[d] From collectors, in proximity to farms and fishing areas.
[e] 300-gram plastic punnets.

metamorphosis. The PL (PL10) selling price in 1999 was US$ 25/1000, up some 44% from a decade earlier.

Most of the farms operate their own nursery ponds or use one grow-out pond for this purpose. Nursery facilities are stocked up to a maximum of 570/m^2 for 2 to 3 months during winter (16–22°C) or 250/m^2 in summer (>23°C) when artificial habitats are employed (horizontal layers of netting). Sometimes palm tree leaves are used as habitats and stocking is 120 to 200/m^2. Over a 2- to 3-month period, survival exceeds 70%.

For grow-out, stocking rates in monoculture are initially 22 nursed juveniles/m^2; density is reduced to about 10/m^2 after 3 to 4 months. One to two prawn juveniles/m^2 (nursed from PL10 for 2 months) are used in polyculture. In this system, 1 to 2 g tilapia fry are initially stocked at 12/m^2 and reduced to approximately 5/m^2 at 200 g, and again to 2/m^2 at 450 g. During tilapia transfers, prawns are either left in the ponds or re-distributed. Grow-out ponds are typically rectangular and 0.2 to 0.5 ha. A commercial feed costing US$ 440/t and achieving an FCR of 2.5 : 1 is employed. In the polyculture system, prawns eat uneaten fish feed (the water stability is poor) and weak and dying tilapia. Fertilisation with cow manure is normal but triple superphosphate or complete NPK fertilisers are occasionally used. Following control over the water inlet supply, the pond water remains green without a heavy bloom, provided the water supply holds out. In periods of drought aerators are used. One farm (for example) has its own reservoir, 2 km distant, but obtains 70% of its water from a hydroelectric plant that ceases to release water during the droughts experienced every 3 to 4 years. No other grow-out problems were reported.

Cull-harvesting occurs throughout the year, with each pond being drained down once annually, usually in winter (July–September), when undersized animals are transferred to other ponds and reared on for the Christmas–New Year market. A elaborate stocking strategy is employed by the major farm to ensure that it has prawns to sell year-round; the harvest size is 30 g. Prior to 1993, some 20% of national production was exported to the neighbouring French island of Réunion. Since then all has been sold domestically, partly because of local demand but also because it was necessary to upgrade processing facilities to meet HACCP (Hazard Analysis and Critical Control Point) and EU standards. Traditionally, about 50% of the harvest currently (1999) goes directly to hotels and restaurants and 25% to wholesalers, while 15% is sold at the farm gate and 10% goes to local retail markets. However, this pattern is changing, because the largest farm now buys most of the output of the other farms and has invested in a processing plant, used mainly for cleaning, grading and packing, since most of the products are sold fresh on ice. This plant already has its HACCP certificate and has achieved EU standards, enabling it to export prawns. Prawns are transported in refrigerated trucks in plastic crates holding 10 kg, with a thick flake ice covering. However, expansion in the areas used for grow-out may be difficult since all farms are owned by sugar cane estates, which regard aquaculture merely as a form of agricultural diversification; the major land use is expected to remain allotted to sugar cane production.

17.5.1 Other African countries

Production in **Egypt** peaked at 10.5 t in 1996, having risen from 2 t in 1992, but declined to less than 1 t/yr in both 1997 and 1998. The 1996 total comprised 7 t from monoculture, 3 t from polyculture with tilapia (*Oreochromis niloticus*), and 0.5 t from experimental integrated farming (rice, fish and prawns). In 1995 there were four farms growing freshwater prawns, including one between 0.4 and 0.9 ha and two between 2.0 and 4.9 ha. No official national production was reported to the FAO during these years. In 1999, the remaining farm, a 1000 ha farm, which has 51% government and 49% private ownership and primarily rears mullet, tilapia, sea bream, sea bass and marine shrimp, was still using about 5 ha to rear a small quantity of *M. rosenbergii* in polyculture with tilapia and mullet. Similarly, the five hatcheries that grow-out farms operated in 1995, with a total capacity of 3 million PL10/yr, have declined to one, with a 0.5 million/yr capacity. The original broodstock came from Hawaii, Malaysia and Thailand. The four abandoned hatcheries were in the Nile delta. The remaining hatchery on the Mediterranean coast operates a clearwater, flow-through system, stocked at 30 larvae/L. The extremely high prices for PL10 (US$ 44/1000), PL30 (US$ 60/1000), and juveniles (US$ 90/1000), have remained steady over the

1990s and clearly inhibit any expansion of the sector. These high costs result from the use of facilities not specifically designed for prawn culture but intended to produce tilapia fingerlings. However, marine shrimp hatcheries exist and sell shrimp PL at US$ 30/1000 (1999); prices are expected to fall to US$ 23/1000.

Egyptian nursery ponds are stocked with freshwater prawns at 2000 to 3000 PL10/m^2. Grow-out ponds are rectangular and 0.4 to 0.6 ha, typically stocked with 0.3 g PL15 at 5/m^2 or 2 g juveniles at 2/m^2. Ponds in polyculture are stocked with 2 juvenile prawns/m^2 and 1 g tilapia fry at 2500/ha. The culture season is restricted, starting in April and ending at the latest in November. Winter water temperatures decline to less than 10°C. Normally, only agricultural drainage water is permitted for use in semi-intensive aquaculture in Egypt; this water is partially saline (1.8–3.8 p.p.t.). In addition, most water with a salinity of <1 p.p.t. is re-used for irrigation and the water available for aquaculture can be as high as 10 p.p.t. It has been locally recommended that incoming water should not be used for freshwater prawn grow-out if it exceeds 5 p.p.t. The supply of the existing farm (1999) has a salinity of 5 to 7 p.p.t. and water in the ponds reaches 10 to 12 p.p.t. A 30% protein farm-made feed (costing US$ 620/t), which incorporates 20% fish flesh is used, along with a 30% protein commercial tilapia/prawn feed (US$ 440/t). When the rearing water is 1 p.p.t., FCRs of 2.3–2.8 : 1 in monoculture and 1.9–2.1 : 1 in polyculture have been achieved. However, at higher salinities (10 p.p.t.), FCR deteriorated to 4.1 : 1 for monoculture and 4.2–4.5 : 1 for polyculture. These results are the conclusions of research studies on several of the original farms. Cow and poultry manures, as well as urea and triple superphosphate, are used as fertilisers. Prawns are harvested by draining the ponds (batch culture). About one-third of the production goes to wholesalers, while the bulk is sold at the farm gate. All production is consumed domestically.

National production in Egypt is not expected to increase unless the private sector can be convinced to operate a hatchery specifically designed for freshwater prawns, not tilapia, which would reduce the extremely high cost of PL. A pilot-scale hatchery, using the technology used in major prawn producing countries, could stimulate such a development. Problems also exist in domestic marketing, since freshwater prawn production has been sold as an alternative to the favoured marine shrimp, but at similar high prices. In addition, Egyptian consumers will not purchase freshwater prawns unless the claws are removed.

Farmed freshwater prawn production of 4 to 8 t/yr was reported to the FAO by **Malawi** in the years 1984–1988. From then until 1995, in-house FAO estimates ranged from 6 t to 3 t per year. The original stimulus was a JICA (Japan International Corperation Agency) built hatchery at Domasi. A commercial company at Sucoma grew prawns with carp and tilapia. However, the hatchery failed and it appears that there has been no commercial production of freshwater prawns in Malawi during the whole of the 1990s. Less than 1 t/yr was included in the FAO data from 1996–1998.

In 1991, a single hatchery produced 1.5 million PL, while two farms totalling 8 ha produced 4 t of *M. rosenbergii* in **Réunion**. Production has not altered significantly since, with 4 t being reported to the FAO for the year 1997 and 3 t in 1998.

The production of farmed *M. rosenbergii* in **Senegal** more than doubled from 2 to 3 t/yr in the period 1988–1991 to 6 t in 1992. Further expansion to 10 t and 11 t occurred in 1993 and 1994, respectively. Production has again more than doubled to an average of 22 t/yr in the period 1995–1998.

A freshwater prawn farm formerly operated a monoculture system in ponds in the Northern Province of **South Africa**, with an estimated production of 4 t in each of 1993 and 1994. Postlarvae were produced by a local hatchery. The target market was restaurants and hotels. However, this farm has since closed. Freshwater prawn farming is not expected to be revived in South Africa, partly because water temperatures are generally unsatisfactory for this purpose and partly because of a domestic consumer preference for marine shrimp. In spite of this report, South Africa imports freshwater prawns (Table 17.1).

Neighbouring **Mozambique**, now a recipient of South African investment, was thought to have a better potential for development than South Africa itself. However, the disastrous floods experienced by Mozambique in the first quarter of 2000 are likely to delay the realisation of such expectations.

Production of freshwater prawns commenced in **Zimbabwe** in the 1970s and national production was reported to have increased to a maximum of 13 t in 1988. The FAO has continued to report an in-house estimate of 15 t for every year from 1994 to 1998 but this is likely to be merely a carry-over of information. The original farm re-directed its activities to finfish and now produces 5000 t/yr of tilapia. In a survey of 50 to 60 farms in 1995–1996, none reported any farming of *Macrobrachium*.

Interest in the farming of *M. rosenbergii* has been shown in several **other African countries**, including Côte d'Ivoire, Ghana, Mozambique, Namibia, and Sierra Leone. Some research work has occurred, but no commercial results or production had been reported up to 1999.

17.6 Europe

FAO statistics show a production varying between 1 and 20 t/yr of 'freshwater crustaceans not elsewhere included' in the **Russian Federation**, but the species cultured is (are) not named. Following the import of two adult female prawns from Vietnam in 1992, commercial farming of *M. rosenbergii* was initiated in Astrakhan in 1997 (the only example known in Russia), using fish ponds ranging from 0.5 to 2.0 ha. This farm is claimed to be the most northerly prawn-rearing farm in the world. The 1998 harvest was a modest 350 kg but expansion plans are under way. The farm expects to produce 1 t in 1999 and is bullish about its future, since demand exceeds supply. An 0.8–1 million PL/yr capacity recirculation hatchery commenced operation in 1998. Postlarvae costs are estimated at US$ 40 to 60/1000. Deteriorating broodstock performance has been observed and new imports of sexually mature animals were being sought in 1999. Currently (1999), production appears to be based solely on natural productivity and the grow-out season is extremely short (~3 months). The harvested animals are mainly sold in restaurants. This pioneering enterprise hopes that production will increase, due to the entry of other farmers and to the use of supplementary feeds and polyculture.

Various reports of research and development or hatchery activities have appeared in the literature concerning work with *M. rosenbergii* in Belarus. Germany, Greece, Iceland, Italy, and Sweden. Early work in the UK has been mentioned in Chapter 1. At one time, FAO statistics showed production in France in 1996 and 1997, and in Portugal in 1994 but these figures have now been removed from the database. In the case of France, the discrepancy was caused by the double reporting of production from its overseas territories. The figure for Portugal had been based on an estimated output from one unit that did not materialise.

17.7 Oceania

Though *M. rosenbergii* was the main species for aquaculture in **Guam** in the mid-1970s, it has been replaced by penaeid shrimp, tilapia and milkfish farming over the last 10 years. Little freshwater prawn farming activity occurred in the final decade of the 20th century. What little occurs (1999) is in the southern portion of the island, where there is access to surface waters (rivers). Currently there is only one farm (>2 ha) which rears prawns but two other owners are interested in establishing small (<0.4 ha) grow-out facilities. Production in Guam was 0.8 t in the first 6 months of 1999. Some 90% of production is in brackishwater. National production is expected to expand slightly because there is a small niche market waiting to be filled. Postlarvae are available from a government hatchery (which also produces penaeids). Freshwater prawn PL are also made available from this hatchery for potential aquaculture developments in the Northern Marianas and the Federated States of Micronesia. Currently the hatchery can produce a maximum of 600 000 PL/yr within a multi-species production and research programme but there is potential for expansion if demand warrants it. Broodstock are obtained from grow-out ponds and the coastal hatchery operates a clearwater closed recirculation system stocked at 25 to 35/L. Postlarvae have been sold at US$ 30/1000 throughout the 1990s. No nursery ponds are employed. Grow-out ponds, typically rectangular and 0.25 ha, are stocked at $15/m^2$. Commercial feed is purchased at US$ 750/t and achieves an FCR of 3 : 1. Triple superphosphate (16 : 16 : 16) is used. Maintaining good water quality appears to be the major management problem. Animals are selectively culled over a period of several months, before the ponds are drained for a final harvest. Some 50% of the production is sold directly to consumers in a public ('flea') market, while 40% goes to local retail markets and 10% is sold at the farm gate.

Since 1988, one farm in **New Zealand** has pioneered the commercial production of freshwater prawns (*M. rosenbergii*) in geothermally heated water. The fact that prawns will not breed in the temperate waters of New Zealand was a prerequisite for the original import of this non-indigenous species. Any further expansion, either by this farm or others, must therefore be based on the use of geothermal water or waste energy sources (e.g. electricity production). So far, no production from New Zealand has been reported by the FAO but the farm, which produced 3 t in 1993, has expanded steadily, reaching 5 t in 1996 and just over 10 t in 1998. This farm, which is situated in the centre of North Island, produced 12 t in the first half of 1999. No disease problems have been experienced at any stage in its integrated production cycle. The farm, which was 6 ha in 1999, with 19 ponds of 2000 to 4000 m^2 area, has commenced negotiations to build two satellite farms increasing the area to 75 ha, so substantially increased annual production is forecast. The product is regarded as 'environmentally clean', with considerable potential for expansion. The original broodstock were imported from Malaysia.

Nowadays, broodstock are obtained from the New Zealand farm's own grow-out ponds, and placed in brackishwater to spawn. The inland hatchery has a capacity of 9 million PL/yr. Larvae are stocked at 150/L in a clearwater recirculation system. No PL are sold. Nursery ponds are stocked at 1000 PL/m^3, while the rectangular (100 × 20 m × 1 m deep) grow-out ponds are stocked at 10/m^2. A commercial feed (US$ 656/t) with an FCR of 1.5 : 1 is used. Ponds are limed and fertilised with urea. In 1999, production was 2.5 to 3.0 t/ha, which was felt to be high enough to warrant expansion of the farm. The farm is experimenting with prawn–grass carp polyculture. The farm's water supply comes from two sources: a plate heat exchanger at 55°C (250 m^3/hr in summer and 400 m^3/hr in winter) and river water at 10°C. Some 90% of the water is recirculated from a settling pond kept at 21°C and the grow-out ponds require little treatment between cycles. The geothermal water, which comes from the Wairakei power plant, cannot be used directly because of its high sulphur, lithium and arsenic contents; thus the use of heat exchange. Each pond is batch harvested twice per year by draining. This process takes a maximum of 12 h and harvests 90% of the prawns; the remainder is manually harvested. Prawns are put through a high-volume cold water wash and then into an ice slurry at 1°C for 2 to 3 h before processing commences. Previous reports indicated that 10% of the product was being sold at US$ 12.6/kg (30–40 animals/kg) wholesale and US$ 20.2/kg retail to gourmet restaurants in major cities but a more recent report states that the whole of the farm's production is sold in its own on-site restaurant. The farm has more than 25 000 visitors annually and provides a half-hour hatchery tour throughout a 5-hour daily period. Fifty per cent of its visitors are foreign tourists.

Some research and development activities have occurred in **Australia**; there were some attempts to farm *M. rosenbergii* in the early and mid-1980s in Queensland, the Northern Territory and Western Australia. None of these commercial ventures was successful. More recently there has been some renewed interest in this topic but no project has yet been implemented. There are plans to investigate its potential in Western Australia in 2000.

Following pre-1990 research and development activities in **Fiji**, commercial production was around 90 t/yr in 1993 through 1996 but fell to 40 t/yr in 1997 and 1998. In 1991 there were four freshwater prawn farms in **French Polynesia** (Tahiti), totalling 14 ha, and one hatchery. Three million PL and 18 t of prawns were produced. In 1998, production was reported to be only 2 t. The FAO reported some farming activity in **New Caledonia** but the production was less than 1 t in 1998. Though there used to be a freshwater prawn farm in the **Solomon Islands**, it was reported to have converted to penaeids at the beginning of the 1990s. No production was reported in this country in 1999, though there is a subsistence fishery. Minor research and development activities have been variously reported in the Federated States of Micronesia, Palau, Vanuatu, and Western Samoa.

17.8 Product value

Examples of 1999 farm-gate values for *M. rosenbergii* are presented in Table 17.2 (p. 313). A very wide disparity in product value is evident when farm-gate prices reported from most of the tropical and developing countries listed are compared with those that are either developed countries (USA) or are associated with them (French Polynesia, Guadeloupe, Guam, Martinique).

Considerable information about current (1999–2000) prices for *M. rosenbergii* in retail outlets has also been gathered from the questionnaires (Table 17.3, p. 316). As expected, retail prices in those developed countries that import freshwater prawns tend to be much higher than those in the producing nations. However, there are also some disparities between the producing countries themselves. Freshwater prawns appear to be quite cheap in the retail outlets of several major producing countries where most are sold live or fresh and head-on (e.g. China, India, Thailand, Vietnam). Retail prices in Bangladesh for head-on prawns seem rather higher than in India. For example, live 200 g prawns were on the market for US$ 13.1/kg in Bangladesh, whereas 100 to 150 g fresh head-on prawns were being sold for only US$ 2.3 to 2.5/kg retail in India. Most prawns appearing in retail outlets in Bangladesh are sold head-off. This may reflect the fact that Bangladesh is a major exporter of (mainly head-off) wild and farmed freshwater prawns. In Brazil, as might be expected from such a large country with differing local standards of living, the product is much cheaper in some areas than in others. Head-on prawns (20 to 30 g) are obtainable fresh for US$ 5.5 to 6.6/kg in the Northeast and US$ 5.2 to 7.2/kg in Espírito Santo State (the main production area). However, the price for head-on frozen prawns of this size in Porto Alegre is US$ 15.0 to 18.0/kg.

The retail value of head-off freshwater prawns in Belgium and the UK is extremely high, which may explain why these countries are major destinations for head-off prawns from Thailand (Table 17.1). There is also a good market for head-on Thai prawns in certain countries, notably France and Italy. As noted elsewhere in this chapter, the farm-gate (Table 17.2) and retail (Table 17.3) prices for locally farmed prawns in French Polynesia, Guadeloupe and Martinique are high, which precludes the development of an export market (even to metropolitan France, where retail prices appear cheaper) and causes problems for local farmers in competing with imports of cheap frozen prawns from Asia. Prices in Mauritius seem lower than in the French Departments and Territories but more expensive than in Asian producing countries or in Brazil.

The disparity between the prices at which freshwater prawns are available, either at the farm gate or in the retail outlets of many producing countries, and those obtainable in countries that import this product, is generally substantial. This illustrates the considerable potential for the expansion of the farming and processing of freshwater prawns for export that exists for many tropical countries. Some countries, notably Bangladesh and (less so) Thailand and Vietnam, are already taking advantage of this opportunity. Opportunities also exist for other producing countries, particularly China, India and Brazil. Such opportunities could probably be increased if the product was properly marketed in major seafood importing countries (e.g. Japan, USA, and the members of the EU).

17.9 Citations

The following published information was used to supplement the information provided by the questionnaires and ensuing correspondence. *Global*: FAO (1989a,b, 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997, 1998, 1999, 2000), New (1990, 1995); *Bangladesh*: Anonymous (1997a; 1999), Ahmed (1998), Akand & Hasan (1992); *Brazil*: Valenti (1998); *China*: Cen & Zhang (1998), Xinping *et al.* (1998), Wang & Qianhong (1999); *Dominica*: New (1978), Weidner *et al.* (1992); *Dominican Republic*: Weidner *et al.* (1992); *Colombia*: Weidner *et al.* (1992); *Ecuador*: Weidner *et al.* (1992); *Egypt*: Sadek (1998), Sadek & Moreau (2000); *El Salvador*: Sandifer *et al.* (1992); *India*: Anonymous (1997b), Murthy (1998); *Indonesia*: Taw (1997); *Malaysia*: Ang (1989), Singh & Vijiarungam (1992); *Myanmar*: Anonymous (1996), Taw (1997); *New Zealand*: Lund & Klein (1998); *Pakistan*: Yaqoob (1994), New (1996); *Paraguay*: Weidner *et al.* (1992); *Taiwan*: Lo & Hwang (1994); *Thailand*: Boonyaratpalin & Vorasayan (1983), Tunsutapanich *et al.* (1997); *USA*: Lienau (1991); *Venezuela:* Jory *et al.* (1999); *Vietnam*: Hien *et al.* (1998).

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18

Post-harvest Handling and Processing

Raúl M.M. Madrid and Harold Phillips

Correct handling and post-harvest treatment is fundamental to the economic success of farming *Macrobrachium rosenbergii*. Mistreatment can result in a severe reduction of product value. Deterioration in freshwater prawns first affects texture; an unpleasant smell follows. The prawns need to be handled correctly from the moment of harvest until preparation in the kitchen and consumption.

If prawns are not to be sold live, it is necessary to ensure that they are killed rapidly after harvesting. This can be achieved by chilling immediately after being washed and disinfected. If the prawns are to be sold chilled within 4 days, they can be maintained at 0°C. If they are to be quick frozen, they need to be maintained at –35°C. They can be maintained frozen without significant quality loss for up to 6 months.

The consumer needs to be satisfied with the product. *Macrobrachium rosenbergii* is a species that may be considered a 'new' product in many parts of the world. It is vital that its purchasers have a positive impression of the product and that this impression is maintained throughout the distribution channels. Product image may take years to build, but can be destroyed in a very short time.

This chapter presents the intrinsic characteristics of *M. rosenbergii* in terms of its composition and yields, its flavour and texture characteristics, and the effects of the deterioration phenomenon and specific processing treatments.

18.1 Intrinsic characteristics

18.1.1 Composition

The proximate composition of various sizes of *M. rosenbergii* was analysed by Lobão *et al.* (1988) who reported average values of 76.2% moisture, 20.7% protein, 0.7% lipids, and 1.2% ash. Chanmugam *et al.* (1983) reported a higher content of lipids (3.18%) in the freshwater prawn *M. rosenbergii* than in the marine shrimp, *Penaeus (Farfantepenaeus) aztecus* (1.33%). This observed difference in lipid levels was due to the higher concentration of triglycerides in *M. rosenbergii* (730 mg/g fat) than in the marine shrimp (213 mg/g fat). The n-6 polyunsaturated fatty acid (PUFA) content was higher in the freshwater prawn while the n-3 series PUFAs were higher in *P. aztecus*, mainly due to the great concentration of linoleic acid in the former (16.2% *versus* 2.9%). These workers found a level of 1.13 mg/g of cholesterol in the tail meat of *M. rosenbergii*, whereas *P. aztecus* contained 0.90 mg/g. Contrary to the findings of Chanmugam *et al.* (1983), D'Abramo (1993) reported that *M. rosenbergii* has lower levels of cholesterol than marine shrimp; freshwater prawns also have lower levels of iodine than marine shrimp or marine fish. Silva *et al.* (1989) reported that the cholesterol content of prawn tail tissue ranged from 0.71 to 0.98 mg/g compared to 1.25 mg/g in marine shrimp, while iodine values were 0.14 p.p.m. for medium-sized prawns (30 g whole weight) compared to 0.80 p.p.m. for marine shrimp and 0.83 p.p.m. for marine fish. These findings indicate a possible means of promoting freshwater prawns as a healthy product.

18.1.2 Yield

The yield of *M. rosenbergii* depends on its sex and size (New 1990). As the size increases, the percentage of tail meat decreases. Females yield a significantly larger proportion of tail meat than males, independent of size. The claws of females are small and have a relatively constant relationship to the total weight (2.8%). Male claws are larger, and the claw percentage increases with the size of the male. Thus, in males of 20 g the claws are 4.3%, while in 100 g males the proportion is 14.3% (Smith *et al.* 1980). The yield of *M. rosenbergii* tail meat is lower than that of marine shrimp (47.6% as opposed to 62.9%). The freshwater prawn yield of edible meat, however, is greater than other crustaceans and fish such as lobsters (36%), crabs (15%), tilapia (35%) and mullet (41.9%) (Smith *et al.* 1980; Contreras-Guzmán 1995).

18.1.3 Flavour

The production, processing and distribution of products originating from aquaculture are more controllable than those from capture fisheries. Thus, parameters which affect flavour can be more effectively controlled. However, there has been little research on this topic (Johnsen 1989). Morh (1986) concluded that more knowledge was needed concerning the relationship between cultivation methods, nutritional factors and the quality of fish in general, since information at that time was very limited, indicating a potentially valuable area for future research. The flavour of fish, crustaceans and molluscs originates from extractable compounds of low molecular weight that are soluble in water or saliva during mastication. These substances are more abundant in crustaceans and molluscs than in fish, which accounts for what many would regard as their superior palatability (Konosu & Yamaguchi 1982).

The extractable compounds can be divided into two major groups. The first category comprise the component non-protein nitrogen (NPN) which mainly includes free amino acids (FAA), quaternary ammonia compounds and nucleotides. The second category includes non-nitrogenous compounds such as organic acids, sugars and inorganic compounds.

18.1.3.1 Role of free amino acids

Free amino acids (FAA) may be used as a parameter to determine bacterial deterioration. They are also an important part of the 'typical shrimp flavour' (Rangaswamy *et al*. 1970). According to Robertson & Cowey (1992), FAA present in the muscle are a balance between those supplied from the digestion of proteins, those liberated from the breakdown of cellular proteins, and those used for protein synthesis and as an energy source.

The muscle extracts of shrimp and lobster are similar to other marine invertebrates. These are characterised by the large amount of free glycine (Konosu 1979). Yamaguchi & Watanabe (1990) observed that the content of free glycine was directly related to the flavour of marine food, suggesting that this amino acid has an important part to play in the sweet flavour of crustaceans. Alanine, proline and serine also produce a sweet flavour (Birch & Kemp 1989), contributing to the characteristic shrimp taste. Glutamic acid does not produce a sweet flavour but it enhances the effect of other amino acids (Maga 1988).

Work by Reed & D'Abramo (1989) indicated that the amino acids responsible for the 'typical shrimp flavour' noted above (namely glycine, alanine, proline and serine, together with the enhancer, glutamic acid) constituted up to 70% of the total FAA of tail muscle tissue when freshwater prawns were fed standard reference diets. The FAA of *M. rosenbergii* are qualitatively similar to those found in marine shrimp, but prawns have a more subtle flavour than marine shrimp, a characteristic which provides chefs with more culinary options and may be compared to the difference between veal and beef.

18.1.3.2 Effects of the rearing environment

In addition to the intrinsic factors of genetic load or heredity, the composition of extractable compounds is influenced by salinity, feeding, season, origin and freshness (Konosu & Yamaguchi 1982). Flavour is one of the most important elements of food quality. It has been demonstrated that FAA aid in the osmoregulation in aquatic animals (Gilles 1979) and that they are the key ingredients of flavour (Konosu & Yamaguchi 1982). Thus, increases in the salinity of the rearing environment may result in prawns with a better 'characteristic flavour'.

Besides the amino acids, inorganic ions and salinity content play an important part in the osmoregulation of aquatic animals. The effect of salinity on FAA content and flavour has been demonstrated in a number of shrimp and finfish. Papadopoulos & Finne (1986) studied the effect on these components after the acclimation of *P. aztecus* to salinities of 10 p.p.t. and 50 p.p.t. The shrimp that were exposed to diluted and concentrated marine water had an increase and a decrease in the moisture content of their tails, respectively. On the other hand, the amount of chloride in the tissue increased with increasing salinity. These workers also studied the effect of salinity on the flavour characteristics of *Penaeus (Litopenaeus) vannamei* and demonstrated a difference between those placed in 10 p.p.t. compared to 50 p.p.t. and between those in 30 p.p.t. compared to 50 p.p.t. However, no significant difference in flavour was detected between those in 10 p.p.t. and 30 p.p.t. Similar results were obtained in FAA content. Gerard & Gilles (1972) observed that the FAA of the crab, *Callinectes sapidus*, fell from 416.25 to 301.81 mMol/kg (wet weight) when transferred from seawater to a 50:50 mixture of seawater and freshwater. The level of glycine, the amino acid most responsible for flavour, declined by 22%. Fish also experience alterations in body composition when they are transferred from freshwater to seawater. Although flavour changes have not been documented, Venkatashari (1974) observed that the level of FAA in *Oreochromis mossambicus* increased from 552 to 1009 mg/100 g of muscle when transferred to seawater. Daikoku & Sakagushi (1992) verified that the content of trimethylamine oxide increased from 2 to 12 mg/100 g when *Anguilla anguilla* was transferred from freshwater to seawater.

Working with *M. rosenbergii*, Madrid (1994) studied the effect of the osmoregulation process and feed on flavour, by comparing the flavour of *M. rosenbergii* fed on an enhanced diet and subjected to various salinities with the flavour of prawns fed a non-enhanced diet and kept in freshwater and the flavour of *Penaeus (Farfantepenaeus) paulensis* fed normal feed and kept in seawater. In each case the prawns or shrimp were microwaved and offered to a trained taste panel. After 5 days of feeding *M. rosenbergii* on the diet containing traditional ingredients enhanced by flavour precursors and other substances included to reduce the effect of osmoregulatory stress (glycine, sodium chloride, potassium chloride, lecithin and glucose), prawns were placed in aquaria containing water of 10 p.p.t., 20 p.p.t. and 25 p.p.t. salinity for 72 h. At 10 p.p.t., the flavour of the freshwater prawns was not altered significantly; *M. rosenbergii* is a strong hyper-regulator at this salinity. However, after only 24 h at 20 p.p.t. and 25 p.p.t. salinity, the extractables increased to an amount similar to that in the *P. paulensis*. The control *M. rosenbergii* were given a slightly negative taste evaluation, while the *P. paulensis* were given a strongly positive evaluation. After 48 h at 20 p.p.t. and 25 p.p.t. salinity, there were no significant differences in terms of taste between the freshwater prawns and the marine shrimp. The effects of seawater acclimation on the chemical and sensory properties of adult *M. rosenbergii* have also been studied by Weng *et al.* (1997). Salt and FAA content of prawns increased steadily throughout the test period in seawater-acclimated prawns. At first (<18 h) their moisture content initially decreased but later increased during the trial period. Significant differences in flavour were detected between baseline (0 h) and seawater-acclimated prawns. However, taste panellists could not distinguish between prawns acclimated for 18, 36, or 54 h. The panellists expressed a preference for seawater-acclimated prawns. Thus, seawater acclimation, even for as short a period as 18 h, significantly improves the flavour of freshwater prawns. Such acclimation procedures clearly make the flavour of freshwater prawns resemble that of marine shrimp. However, this is not necessarily desirable. *Macrobrachium* should be marketed as a distinct product, rather than a direct competitor to marine shrimp, by emphasising its subtle flavour. In some cases products with an intense flavour limit cooking options.

Generally, the flavour of aquatic species is attributed to low molecular weight water-soluble compounds, composed of NPN and inorganic salts. No effect has been established for lipids (Konosu & Yamaguchi 1982). Seasonal variation in the extractable compounds of adults is related to the period of spawning in some species. If this applies to freshwater prawns it might have an impact on the management of size variation (see Chapter 16) and harvesting.

Few studies have been carried out on the effect of feeding on the flavour of crustaceans. Japanese importers recommend Taiwanese marine shrimp producers to use a special diet, of a specific commercial brand, to enhance their flavour (S. Eys, pers. comm. 1990). On the other hand, Reed & D'Abramo (1989) reported that there is no relationship between the amino acids supplied in the diet and the FAA found in the intracellular liquid of *M. rosenbergii* prawn muscle. In any case, it is possible that, should dietary composition be shown to affect the flavour of *M. rosenbergii*, feeding a special diet may only be necessary for a few days before harvest.

18.1.3.3 Influence of handling and processing

Freshness is a major factor influencing flavour; however, the flavour of some species improves some time after death. This can be explained by a great diversity of (mainly enzymatic) reactions that cause increases or decreases in FAA, nucleotides, etc., during storage (Kietzman *et al.* 1974; Konosu & Yamaguchi 1982; Carneiro 1992 *apud* Assad 1997). Thomson *et al.* (1980) recommended that it is necessary to identify the compounds that, after cooking, produce the flavour of the species before studying the storage of seafood. The changes that occur in flavour during storage can then be better understood. Though almost no specific studies on the influence of handling and processing on the flavour of *M. rosenbergii* exist, it is reasonable to assume that studies with other decapods are relevant.

Shrimp and prawns lose flavour while stored on ice. Studies by McCoid *et al.* (1984) established that there is a correlation between the loss of FAA in the tail of the shrimp *Penaeus (Litopenaeus) setiferus* and the increase in the bacterial load. Cobb *et al.* (1974) obtained similar results, but also determined that a great part of the loss of FAA was because of physical factors, not biochemical transformations. When shrimp are placed directly in contact with ice, water leaches soluble substances, such as FAA, from the surface. In this study, the shrimp were also stored on ice, but without direct contact. After 6 days under these conditions, the shrimp had a similar concentration of FAA to the initial state. Cobb *et al.* (1974) observed that the relationship between total nitrogen and N-amino acids did not increase significantly until the level of bacteria reached 10^7/ml. Flores & Crawford (1973) found that the flavour of *Pandalus jordani* improved during the first 4 days of storage on ice. After this period flavour decreased and, at the end of the eighth day, the flavour was similar to that of the first day.

Matsumoto & Yamanaka (1990) observed that the concentration of adenosine triphosphate (ATP) in *Penaeus (Marsupenaeus) japonicus* stored at 0°C decreases quickly, while adenosine monophosphate (AMP) and inosine monophosphate (IMP) accumulate. When *P. japonicus* reaches a K value (an index used to evaluate the quality by means of the degradation of the nucleotides) corresponding to 20%, deterioration has begun. Nakamura & Ishikawa (1986), using organoleptic evaluations, found that *P. japonicus* could be held for a maximum of 3 days stored at 2°C for sashimi or sushi preparation.

Temperature is a very important factor in shelf life. Based on sensory evaluation, Shamshad *et al.* (1990) determined a shelf life of 13 days, 7 days and 3 h for *Penaeus (Fenneropenaeus) merguiensis*, stored at 0, 15 and 35°C, respectively. Shaban *et al.* (1987), studying the effect of different temperatures of frozen storage on *P. japonicus*, concluded that quality is maintained for a long storage period at –40°C. On the other hand, at –20°C, storage is limited to a few months.

Reddy *et al.* (1981) studied the changes in fatty acids and quality of *M. rosenbergii* during frozen storage. The fatty acids, especially the unsaturated fatty acids, experienced a reduction in 6 months at –18°C, but rancid flavours affecting product quality were not detected.

In all the stages of post-harvest handling and processing, adherence to the principles of HACCP (Hazard Analysis and Critical Control Point) is essential, both to ensure quality and to protect the consumer. The appearance of the product is also important. As with finfish, some prawn diseases and parasites compromise marketability. These topics and the dangers of contamination from the medications sometimes used in farming are discussed in Chapter 15.

18.1.4 Texture

Flavour and texture may be inter-related but it is much easier to relate overall texture (as determined, say, by a taste panel) to physical measurements. Texture may be evaluated by sight, touch and taste at the time of mastication. Food is physically broken down during initial mastication and is soon reduced to small pieces before it is ingested. During this process, its size and form changes and its superficial characteristics are noticed (Izutsu & Wani 1985). In meat, flavour and texture are the characteristics that determine its acceptance (Pearson *et al.* 1983). Rasekh *et al.* (1970) stated that the acceptance of cooked fish depends more on flavour than on texture. However, texture is a determinant of acceptance for seafood with subtle flavour characteristics, such as *M. rosenbergii* (Wesson *et al.* 1979). Fish, crustacean and molluscan muscles in general have little connective tissue (though most is collagen), which explains their easy disintegration during cooking (Dunajski 1979). The collagen of *M. rosenbergii* lacks some of the cross linkages, making it more susceptible to enzymatic degradation.

The commercial success of *M. rosenbergii* as a product has been hindered by its short shelf life (only 3 to 4 days) in the fresh chilled form. After this time, *M. rosenbergii* turns 'mushy', experiencing a pronounced loss of muscle integrity, which the consumer does not like (Kye *et al.* 1988). According to Baranowski *et al.* (1984), the production of *M. rosenbergii* was considered a high priority in the 1978 Aquaculture Development Plan of Hawaii but its short shelf life on ice was identified as a limiting factor for its development. After 4 days, the texture of the tail became 'mushy' after cooking. These workers found that this phenomenon was more pronounced in the first tail segment, adjacent to the hepatopancreas. Angel *et al.* (1986a) defined the characteristic termed 'mushy' as a texture which does not offer bite resistance and possesses a floury consistency. Nip *et al.* (1985) identified the term 'mushiness' as the easy separation in flakes ('flaking') of the abdominal tissue of cooked prawns, mainly in the first tail segment, and the total absence of tail integrity in shelled and cooked prawns.

According to Rowland *et al.* (1982), the 1980 US National Aquaculture Plan referred to the problem of *M. rosenbergii* texture. 'Mushiness' had been observed in freshwater prawns imported into the USA, compared to marine shrimp. This and variations in general quality and packing generated a negative opinion of *M. rosenbergii* among importers and caused its value to be deemed less than marine shrimp of similar sizes. Rowland *et al.* (1982) carried out a histological analysis of the muscle tissue of *M. rosenbergii*, revealing that proteolytic action causes the 'mushiness'. After 48 h of storage on ice, freshwater prawn tails exhibited substantial muscle integrity of the Z line and the myofilaments, indicating that the sarcoplasmic proteins were completely intact. Conversely, in head-on prawns, openings in the sarcoplasm were evident. The relationship between the degradation of myofibrillar proteins and textural changes during the storage of *M. rosenbergii* on ice for 14 days were studied by Kye *et al.* (1988). Myofibrillar protein degradation of 113 000, 103 000, and 80 000 daltons, and an increase of the sub-units of protein of 25 000 and 31 000 daltons was observed during the storage period. This increase in proteins of low molecular weight thus coincides with the decrease of those with high molecular weight, meaning that the degradation of the myofibrillar proteins occurred in the first days of ice storage. The disappearance of the alpha-actin band was also observed after the third day of storage. Studies have demonstrated that the alpha-actin is freed from the Z line as a result of a partial myofibrillar degradation caused by a calcium-activated enzyme. This has been one of the main causes of myofibrillar division. The texture loss during the first 3 days coincided with complete break-up of the alpha-actin (103 000 daltons). This variation becomes more evident after the seventh day, culminating with the disappearance of the 80 000 daltons band.

Nip & Moy (1988) found similar results when studying the changes in microstructure of prawn tails, using a scanning electronic microscope (SEM). Measurements were made at 0, 3, 5 and 7 days. The observations showed that prawns at time 0 had an organised muscle fibre structure with intact perimysium and endomysium. After 3 days, the muscle structure of the prawns experienced a partial disintegration of the perimysium and endomysium, which divided the muscle fibre, probably due to enzymatic action. On the fifth and seventh days, both layers had totally disintegrated and were only found in small amounts. Papadopoulos *et al.* (1989) studied the ultra-structural changes that occurred in *M. rosenbergii* held on ice using an electronic microscope and observed that there were no changes 24 h after death compared with the time of death. The myofibrils of the prawn were totally intact and the Z line and the H zone were clearly defined, without any visible loss of structure. After 3 days, some loss in structural integrity was apparent. The H zone became more diffuse, and the Z line began to disintegrate. Ten days after death, myofibrillar integrity was lost and the Z line and the H zone were completely absent. These authors believed that the break-up of the Z line might be an explanation for the development of the 'mushiness' in prawns stored on ice.

Lee *et al.* (1980) studied the specific activity of ten digestive enzymes obtained from the hepatopancreas of *M. rosenbergii* fed with a commercially available feed. This research verified that an extract of the hepatopancreas exhibited significant activity of the following enzymes: amylase, trypsin, chemotrypsin, pepsin, carboxypeptidase A and B, and leucine aminopeptidase, as well as the lipolytic enzymes. This enzyme profile classifies this species as an omnivore. The 'mushiness' of *M. rosenbergii* held on ice is not due to the action of enzymes indigenous to its muscle tissue but is attributed to the diffusion of proteolytic and collagenolytic enzymes originating from the autolysis of the hepatopancreas (Lindner *et al.* 1988). Even so, according to Lindner *et al.* (1989), the proteolytic activity of the hepatopancreas is less efficient than trypsin in the degradation of tissue myofibrillar proteins. The collagenolytic activity of raw homogenised prawns is stronger than bacterial enzymatic activity. Studies by Lindner *et al.* (1988) indicated that trypsin from homogenised hepatopancreas incubated at 0°C with segments of prawn has a minimal impact on mushiness, although fragmentation of compounds of high molecular weight protein myofibrils occurs. The collagenase induces 'mushiness' when there is a small amount of proteolytic activity. The activity of collagenase from the homogenised hepatopancreas is 15 to 40 times more active on insoluble collagen than the trypsin. Thus, the collagenolytic activity diffused after the disintegration of the hepatopancreas may be responsible for the initiation of tissue deterioration which leads to 'mushiness' (Lindner *et al.* 1989). This observation was sustained by the results of a study by Nip *et al.* (1985), who observed an increase in the soluble collagen of prawn muscle held on ice.

It is important to stress that the biological characteristics of the live animal (genetics, chemical composition, muscle structure, shell structure, etc.), as well as post-mortem biochemical processes and handling and processing, have an influence on the preservation of prawn quality. These factors have a major impact on the structural behaviour of the collagen, which in turn influences the mechanical resistance, integrity and rheologic properties of the muscle (Sikorski & Scott 1984).

Nip *et al.* (1985), determined the amino acid profile of insoluble collagen from *M. rosenbergii* and compared it with a similar study by Thompson & Thompson (1968) on the marine shrimp *P. setiferus*. Hydroxyproline and isoleucine levels in the freshwater prawns were respectively 2.5 and 5 times greater than in the marine shrimp. This phenomenon, added to the small amount of glycine (when compared with other crustaceans and molluscs) as well as the lack of hydroxylysine in the insoluble collagen of the freshwater prawns, hinders the formation and stability of the helical triple conformation, as well as the formation of crossings of intra- and inter-molecular fibres. Under these conditions, the muscle texture of the prawns can easily be degraded by enzymatic action. In marine shrimp the development of 'mushiness' is not observed. The texture of marine shrimp is influenced by pH, cooking time, and storage but is not affected by the thawing method or by the concentration of soluble solids in its covering sauce (Ahmed *et al.* 1972).

18.2 Post-mortem changes

Farmed shrimp and prawns are potentially of better quality than those from the capture fisheries. Harvest procedures can be faster and better controlled. In capture fisheries, it is difficult to standardise quality, or the amount caught; in the case of aquaculture it is possible to predict these characteristics accurately. In capture fisheries, many animals die from asphyxia due to the stress of handling and the volume of the catch. Severe delays in getting the product under ice can occur when freshwater prawns are caught from rivers (see Joseph *et al.* 1992). Intense stress provokes production of lactic acid, due to the reduced capacity of the blood to transport oxygen and carbon dioxide; this harms the quality of the meat. When the harvest is appropriately handled in aquaculture, biochemical and microbiological changes are minimised. Since deterioration processes are initiated only after *rigor mortis*, the more it is delayed, the longer the shelf life of the prawns.

18.2.1 Rigor mortis

The biochemical processes occurring during *rigor mortis* are described only in the literature concerning fish but the fundamentals can be extrapolated for crustaceans, with minor modifications. Immediately after death, prawn tails are soft and flexible. After a certain time the muscle tissue begins to harden, a stage that is called *rigor mortis*. Shortly after that, the muscle becomes soft again.

After the death of the prawn, blood circulation stops. This interrupts the flow of oxygen to the muscle tissues. The biochemical processes continue in muscles and tissues under anaerobic conditions. The muscle cells are still in a state of physiological activity; the glycogen, inorganic phosphate and adenosine diphosphate (ADP) are in phase with adenosine triphosphate (ATP) and lactic acid, causing a reduction in pH. Adenosine triphosphate, which is a high-energy compound, produces a shock-absorbing component among the muscle filaments that are separate and soft, and the muscle tissue is still flexible. Cellular enzymes decompose ATP; despite this the cells are still capable of synthesising ATP for phosphorylation of ADP for a few hours after death. The energy for this process is provided by glycogen and the inorganic phosphorus is obtained by creatine phosphate decomposition. When this process ceases, ATP disappears from the cells, thus nothing prevents the intimate association between structural proteins and actinin and myosin. Thus, strong connections among these proteins are formed and muscular contraction is induced, forming actimyosin. The muscle tissue then becomes hard and rigid, the condition described as *rigor mortis*. The speed of ATP exhaustion in the muscle tissue of the prawns is determined by the initial amounts of creatine phosphate and glycogen at the moment of death.

In addition to the impact of the harvesting process, temperature has a preponderant affect on this phenomenon. The higher the stress on the prawns during harvest and the higher the temperature, the less time will elapse before *rigor mortis* occurs and it will be less intense. A lingering pre-rigor phase will correspond to an extensive *rigor mortis*, which is very convenient because in this phase the animals still have their natural defences intact. It produces a slightly acid pH, which inhibits many indigenous micro-organisms and enzymes and, more importantly, the tissue has a closed (contracted) muscle structure, which slows down the rate of enzymatic and microbiological decomposition (Contreras-Guzmán 1995).

18.2.2 Deterioration

Crustaceans deteriorate more rapidly than finfish, due to the high content of metabolites of small molecular weight, as well as the FAA, which are readily available as nutrients for bacteria. The level of low molecular weight compounds varies according to salinity, amongst other factors, which is why most freshwater species have a longer shelf life than marine species. To determine the degree of deterioration, it is necessary to define the parameters that should be considered in the evaluation of changes in quality, to specify the point at which the prawns are no longer edible. It is important to note that quality is defined by the consumer. In other words, if the quality evaluated at the moment of purchase does not satisfy the expectations of the consumer, he or she simply does not buy the product.

The colour, texture and flavour changes that occur during the deterioration process may be accompanied by chemical and microbiological changes, but the absolute values of acceptability are those measured in a preference scale through an organoleptic evaluation. This concept is fundamental in order to understand the progressive biochemical and microbiological changes that happen during storage. A simple form of measuring the organoleptic variations of colour, texture and flavour is to use a hedonic preference scale which ranges from 0 to 10, the lowest figure being very bad and the highest very good.

It is very difficult to separate the intrinsic biochemical processes that are produced in the muscle tissue after the death of the prawns from those associated with bacterial development. The combined effect of the accumulation or elimination of muscle and microbial metabolites produced by autolysis or microbial enzymes provokes changes in the raw material, which are characterised as deterioration.

After prawns die, before microbial growth becomes significant, the main changes that affect quality are caused by nucleotide degradation through the glycolytic cycle. In this phase an intensification of the flavour is produced. Later, progressive loss of pentose-phosphate and degradation of flavour intensifiers, such as inosine monophosphate (IMP), occurs. The transformation of ATP into IMP is produced through glycolytic reactions. In their turn, autolytic enzymes cause the degradation of IMP into inosine. During the decomposition of nucleotides, other nitrogenous compounds also begin to degrade. The speed of this process is increased by the higher concentration of exogenous enzymes that originate from the growing population of bacteria.

While the meat of live prawns is free from microorganisms, the internal and external surfaces (shell and viscera) are loaded with them. During the deterioration process, qualitative and quantitative changes occur in the microbial flora. In warm waters, the mesophyll Gram-positive flora prevail, highlighting such genera as *Micrococcus*, *Corineformes* and *Bacillus*. At the beginning of the deterioration process, there are significant increases in the levels of the genera *Pseudomonas* and *Alteromonas*, which cause the putrid smell characteristic of the degradation of the sulphur-amino acids.

In crustaceans, especially in *M. rosenbergii*, enzymatic activity has a major effect on quality. The enzymes liberated from the digestive glands have specific activities when the prawns are alive but, when the animals die, they promote a deterioration in the meat, causing 'mushiness'. The speed of this action is directly related to storage temperature.

18.2.3 Shelf life

Despite the general consensus that textural changes have been a problem in the development of *M. rosenbergii* cultivation (see section 18.1.4), the information available has not clearly elucidated when this negative characteristic becomes perceptible while the prawns are held on ice.

According to Passy *et al.* (1983), the original quality of prawns, in terms of microbial count and hypoxanthine content, is important. The initial microbial load can be reduced significantly by deheading and intensive washing. Packing in ice prevents desiccation and lengthens the microbial lag phase from 1–2 days to 5 days. Flushing with carbon dioxide and a storage temperature of 4°C extends shelf life by 2 or 3 days (to 8–9 days) without affecting flavour. Cooking tends to remove off-flavours and odours and toughens up the texture of prawns. Reports on the onset of 'mushiness' range from 3 to 8 days of storage on ice (Rowland *et al.* 1982; Angel *et al.* 1985; Nip *et al.* 1985; Lindner *et al.* 1988). According to Angel *et al.* (1985) variations in the time that 'mushiness' becomes apparent can be attributed to differences in raw material sources. It is possible that relative differences in rearing conditions of the prawns have induced stress during growth and harvesting.

A series of studies have been made to evaluate prawn quality. Neither the immersion of prawns in water at 65°C for 15 min or in a solution of sodium hypochlorite (50 p.p.m.) for 1 min (Waters & Hale 1981), nor blanching at 82°C for 3 min (Tillman & Finne 1983) affected the development of 'mushiness'. Similar results were obtained when live prawns were submitted to an 18-hour purification process in flowing water (Nip *et al.* 1985). Although this latter procedure improved the appearance of the product, it caused a mortality of 8%, which makes purification a questionable commercial procedure. Similarly, irradiation (145–230 krad) was not found to have a positive effect on texture (Angel *et al.* 1986b). From these papers it can be concluded that 'mushiness' does not occur due to an increase in proteolytic bacteria, since these only increase after the sixth day of storage on ice, while this loss in textural quality may appear as early as 3 to 4 days of storage on ice. The change in texture cannot be attributed to enzymatic action produced by psychrotrophic bacteria (Premaratne *et al.*

1986). According to Waters & Hale (1981), the characteristic odour of deterioration was detected after 14 days of refrigerated storage, while the prawns had a softer texture, compared to the initial state, after only 4 days on ice. Angel *et al.* (1981) obtained similar results, detecting the odour of deterioration after 16 days.

Prawn quality is not affected by blast freezing, brine or liquid nitrogen freezing, when stored for 1 month at –18°C, according to Nip & Moy (1981). Improvement in texture was observed when prawns were de-headed immediately after harvest (Tillman & Finne 1983). These results were confirmed by Papadopoulos & Finne (1985) but were not found to apply to *Penaeus* spp. (Alvarez & Koburger 1979). Hale & Waters (1981) reported that whole frozen *M. rosenbergii* lost their texture after cooking, following frozen storage for 3 months; however, this did not occur if the prawns had been de-headed before freezing and storage.

Angel *et al.* (1986a) also studied the relationship between the moult stage of *M. rosenbergii* prawn and 'mushiness'. Their results led them to conclude that prawns in the premoult stage seemed more prone to degradation. These prawns have a shorter shelf life because degradation proceeds rapidly, due to the larger amount of proteolytic enzymes and the action of the digestive enzymes of the hepatopancreas. In the postmoult stage, when the prawns have a greater moisture content, the prawns tended to be less 'mushy'. In the intermoult stage, when the exoskeleton and the head are hard, modifications in texture occur more slowly than in the other two stages. Should the induction of synchronous moulting ever become controllable through farm management procedures, this phenomenon could influence the time of harvesting selected.

18.3 Preservation

In their country of origin, many prawns (*M. rosenbergii*) are sold live (see section 18.4). However, depending on the time that elapses between harvest and the sale of the prawns, they are normally maintained refrigerated or frozen, in which cases it is essential to pre-treat immediately after harvest. This section describes the practical techniques (pre-treatments, cooling, and freezing) that need to be applied to harvested prawns in commercial practice.

18.3.1 Preliminary treatment

Stacking of prawns in the net during harvest should be avoided; this causes damage to the internal organs which is accelerated mainly by enzymatic changes. It is not good procedure to cause the prawns to die from asphyxia by leaving them out of water. The prawns need washing with plenty of clean chlorinated water immediately after harvest. Mud concomitantly harvested with the prawns is a source of contamination. Microbial contamination increases 10-fold after 15 min if the prawns are left in muddy conditions (Griessinger *et al.* 1991).

Immersion of prawns in cold water (thermal shock) is the most effective and rapid method to cause death and to cool the prawns individually. Experience has shown that, where supplies are locally and economically available, using full-strength seawater that has been chlorinated reduces the incidence of 'mushiness' in the prawns. It is not advisable to maintain them alive directly on ice or in a refrigerating bed because this procedure promotes a slow decrease in internal temperature, causing stress and accelerating the deterioration process that occurs after death. To promote thermal shock for a batch of 50 kg of prawns it is necessary to immerse them in 50 L of water and 80 kg of ice for 30 min. After this time, they should be removed from the cold water and immediately placed in isothermal boxes, with alternate layers of ice and prawns, placing ice in the first and last layer. Water originating from the ice should not directly contact the prawns (Griessinger *et al.* 1991).

18.3.2 Cooling

Using ice is the most convenient way to cool seafood since it has great refrigerating power and it maintains the humidity and brilliance of the prawns, avoiding the desiccation that would occur if cold air were used. Another advantage of ice, besides being portable, potentially innocuous and frequently inexpensive, is that it solidifies at 0°C, so the prawns can be maintained close to freezing point; thus it acts as a thermostat (FAO 1975, 1994). However, it is essential that the ice used be made from clean water. Such ice is not always available in developing countries and even clean ice can be contaminated after manufacture. Joseph *et al.*

(1992) stated that contamination of ice was commonplace when freshwater prawns were transported to local markets in India. If any doubt exists, it is a good practice to chlorinate the water prior to using it to make ice.

Some farmers who want to maintain their prawns at 0°C immediately consider refrigerated storage. Often, when selling equipment, suppliers oversize the equipment needed, so that the capacity is far beyond the producer's needs. Frequently, chilling and storage facilities are built to reach temperatures of –10°C, when 0°C is all that is necessary. This causes investment, operational, and maintenance costs to be unnecessarily high.

Many prawn producers are able to buy ice close to their farms and often this is all that is required. Ice has many advantages. Water freezes at 0°C. For the water to become ice, heat must be extracted and that same amount must be absorbed before the ice can become water. A kilogram of ice needs 80 kcal to transform it totally to water. Ice, because it can absorb so much heat, is frequently used in the fishing and aquaculture industries. One kilocalorie (kcal) is required to raise the temperature of 1 kg of water by 1°C but to increase the temperature of 1 kg of ice by 1°C, only 0.5 kcal are needed. The capacity to retain heat (specific heat) of water in liquid form is thus 1, while in solid form (ice) it is 0.5. Freshwater prawns, which contain approximately 80% moisture, have a specific heat of around 0.84.

Blocks of ice have an index of storage of 1.4 m^3/t, which means that it is possible to store 714.3 kg of ice in 1 m^3. The melting ice removes 80 kcal/kg. Thus, considering only latent heat (not the heat removed when the ice warms up), 1 m^3 of triturated ice removes 57 144 kcal of heat.

In a refrigeration system, 1 m^3 of cold air (0°C and 90% relative humidity) removes only 8.8 kcal of heat from the product. Therefore, for the same volume, ice has a refrigerating power nearly 6500 times greater than air. Thus, it is not advisable to use refrigeration to cool prawns. Cold air has to pass the surface of the prawns many times to equal the cooling capacity of ice; this can cause dehydration and the cooling process is much slower. Air-cooling requires a larger investment and higher operational costs. To maintain the prawns at 0°C, they should be stored on ice without refrigeration equipment.

Joseph *et al*. (1992) found that keeping prawns on ice for 2 days improved tenderness and flavour. However, by 6 days, a slight loosening of the shell appeared in 30% of the samples, a phenomenon that worsened on subsequent storage on ice. This is important, because prawns are frequently harvested at night in India (and other tropical countries), to reduce harvesting and transport losses, and transported live to the most local market in bamboo baskets lined with matting or palm leaves. When more prawns than can be sold live are harvested, these are iced and transported elsewhere. Often prawns may remain in the market for a day, with over 50 kg packed in single iced containers, stacked one above the other, causing considerable damage to those at the bottom. Damage is particularly caused by large blocks of ice (where this is used instead of flake or crushed ice). Death occurs when the prawns are stressed and out of water, causing quality deterioration. According to these workers, chilling the prawns in water immediately after removing them from water was not normally practised at that time.

18.3.3 Freezing

The decision whether to freeze the prawns or not depends mainly on the time that will elapse before their use. If they cannot be marketed within 5 days of harvest, a period considered the maximum practical shelf life for *M. rosenbergii*, they need to be frozen. Prawns destined for freezing should receive the same care and attention as those destined for fresh sale. Freezing, whether or not preceded by cooking, cannot improve the quality of the prawns. Under the best circumstances, the prawns will have the same characteristics as they had at the moment of freezing.

Preservation by freezing is based on two principles. The first refers to the change of the physical state of the considerable quantity of water present in the prawns from liquid to solid. The second is to ensure that the temperature decreases to such low levels that the growth of micro-organisms is impeded. At temperatures below –10°C, most micro-organisms do not grow. Below –10°C, some enzymes become inactive, autolysis may happen, and its speed depends on the storage temperature (Fig. 18.1).

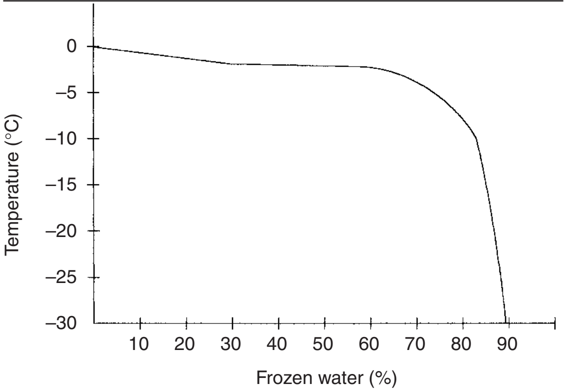

Fig. 18.1 Relationship between temperature and percentage of frozen water in fish muscle

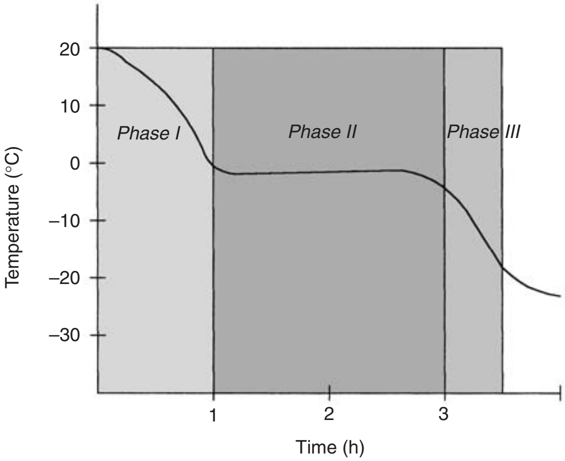

Fig. 18.2 Temperature phases during freezing

Not only temperature, but the speed of freezing is important to prawn quality; *M. rosenbergii* have a more fragile texture than marine shrimp. To avoid physical damage to the muscle structure of the prawns, it is advisable that the freezing temperature passes from –1°C to –5°C as rapidly as possible (not more than 2 h). In this temperature interval most of the water within the flesh of the prawns solidifies (Fig. 18.2). The meat of prawns (as well as other animals) consists of adjacent cells. When the temperature begins to decrease below 0°C, crystal formation begins in the fluids among the cells. The freezing speed determines the size of the crystals. If the temperature decrease is rapid, there is no time for the intracellular fluids to emerge from the intercellular spaces. This causes the formation of small crystals inside and outside of the cells. Freezing in this manner noticeably decreases the production of 'drip' (leak) at the moment of thawing, and conserves the sensory properties of the original product. When the freezing speed is slow, large crystals form in the intracellular water. The level of 'drip' noticeably increases, degrading product quality (Geromel & Forster 1985).

Most small producers use 'domestic freezers' to freeze prawns and for ensuing storage. Even though this is a practical procedure to lengthen the shelf life of the prawns, it can harm the product quality considerably, mainly the texture of the flesh, one of the most sensitive matters concerning *M. rosenbergii*. The consumer does not observe that the texture is soft until consuming the product. The sensation that the consumer has at this time, if there is no 'bite' resistance, can be so negative that the product is not purchased again. When a 'domestic freezer' is used by a small producer to freeze and store prawns, freezing must always be carried out with a small amount of very cold prawns. It is important that they should be in contact with the base of the 'freezer' or the shelves where the refrigerant liquid passes. When the thickness of the layers of prawns increases, the freezing time increases in a geometric proportion.

The best solution is to use special equipment for freezing. According to the Food and Agriculture Organization (FAO 1977), there are four types of freezing:

- *Freezing by fast air circulation*: There are continuous and discontinuous forms. In both cases the heat is removed by a fast current of cold air, which passes through the product. In the first case, the product freezes while slowly passing through a freezing tunnel. In the second, the product is generally placed in trays on small trolleys that stay fixed in a tunnel during the blast freezing process (Fig. 18.3).
- *Freezing by plates or contact*: Transmission of heat occurs through direct contact between the product and the metallic plate through which passes the refrigeration gas. The plates of the freezer may be horizontal or vertical (Fig. 18.4).
- *Freezing by immersion*: The freezer removes the heat of the product through brine at low tem-

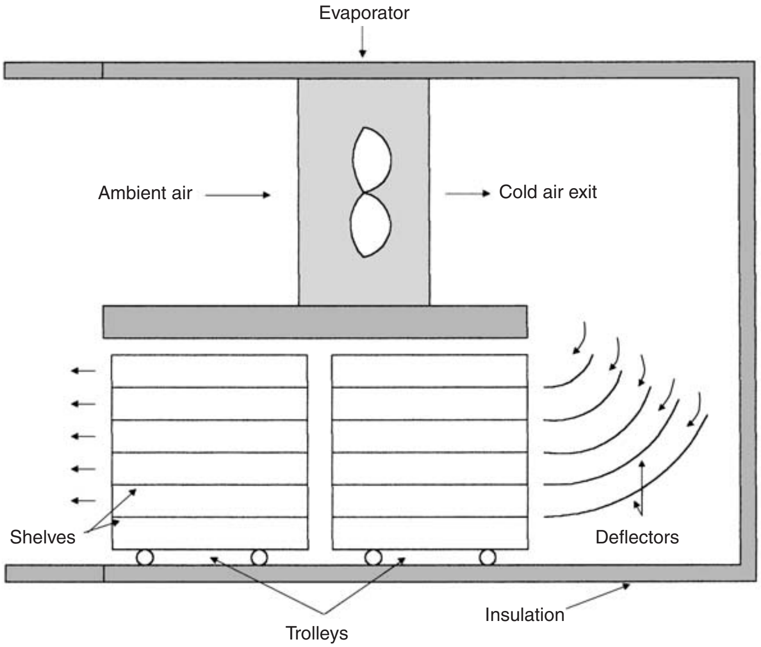

Fig. 18.3 Tunnel freezer

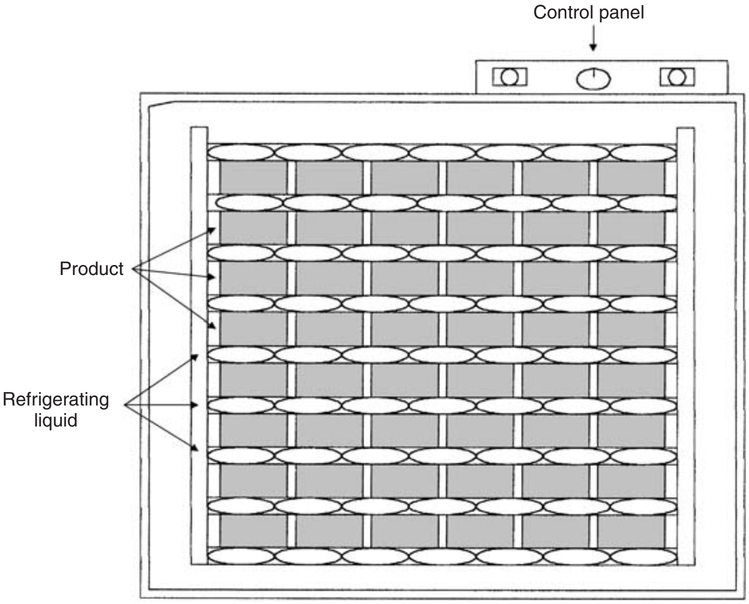

Fig. 18.4 Plate freezer

perature cooled by a coil in which the refrigerant gas circulates (Fig. 18.5). The temperature of saturated brine can go down to –20°C without the product suffering changes of physical state.

- *Cryogenic freezing*: Heat is removed from the product by direct contact with a gas or liquefied vapour (Fig. 18.6). Liquid nitrogen is the one most frequently used.

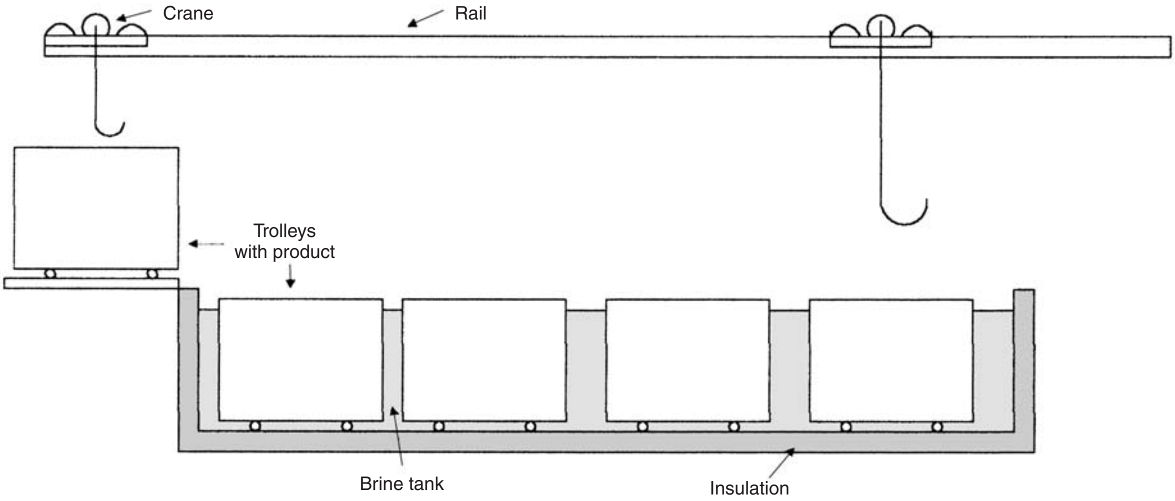

Fig. 18.5 Immersion freezer

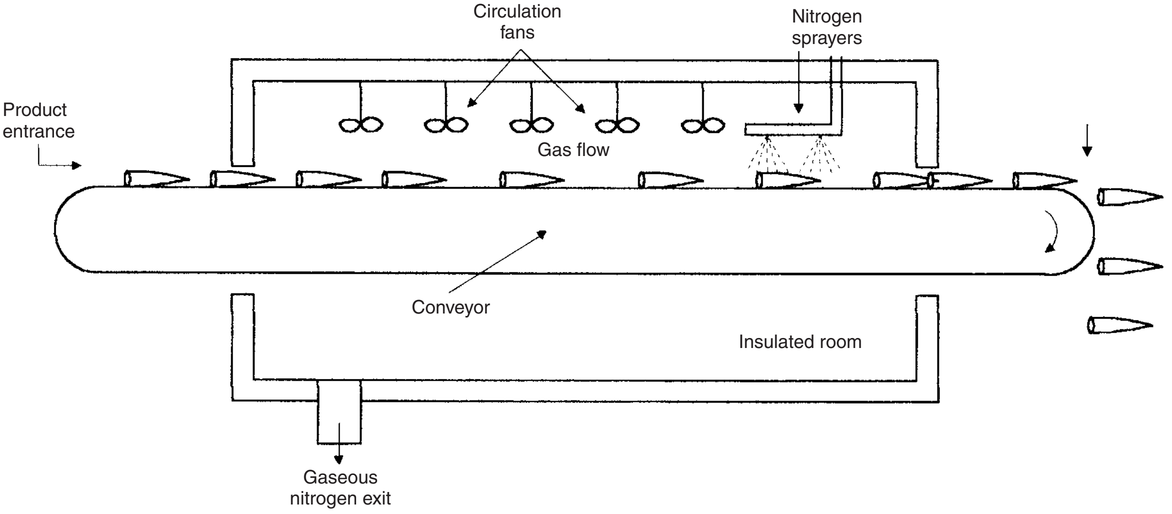

Fig. 18.6 Cryogenic freezer

The form of the product will be determined by the market. The most common form in which marine shrimp is exported to the USA and Japan is as frozen tails in 5 lb (2.27 kg) cardboard boxes. Farmed freshwater prawns are often sold as whole animals. Traditional 5 lb boxes may be used, as well as plastic airtight packaging, etc. Marine shrimp are often de-headed at sea. They are then classified by size, packed uniformly in 5 lb cardboard boxes and properly weighed. A plastic bag is then placed around them to allow the addition of water to form a block. Next, they are frozen either in a tunnel or by the plate system. The added water acts as glazing. The layer of ice protects shrimp from desiccation during storage. The shrimp frozen in these boxes are usually thawed and sold as fresh product or they are reprocessed into a value-added product.

Shrimp and prawns can also be frozen whole if a market exists for this product. Besides the block frozen product, shrimp and prawns may also be frozen in IQF (individually quick frozen) form, by cold air, brine, gas or liquefied vapour. In this case it is necessary to glaze the shrimp or prawns with a fine layer of ice on the surface by immersion in a tank of cold water, never higher than 5°C. This procedure is to protect the prawns from dehydration during frozen storage. These processes can be used for freshwater prawns as well as marine shrimp but it is essential to remember that if the heads of freshwater prawns are not removed (i.e. the market being addressed is for whole animals) the product will become 'mushy' if it is not kept at –20°C.

The deterioration of prawns caused by micro-organisms ceases when their temperature is below –10°C; however, as noted earlier, some enzymatic action continues. The lower the storage temperature, the slower will be the action of these enzymes. In industrial practice, the storage temperature is from –18°C to –25°C in most commercial freezers. Proper glazing is important to avoid colour changes, the desiccation of the surface of the product, and weight loss. A basic principle in successfully storing frozen prawns is that the product first stored should be the first that is used. The producer has an important responsibility for the quality of the prawns from grow-out to consumer. The producer should ensure that frozen prawns are not subjected to significant fluctuation in temperatures during transport and distribution (Geromel & Forster 1985).

An alternative product form is to pre-cook prawns before freezing. Some Brazilian companies sell this type of product. The colour is very attractive and the process deactivates a large percentage of the enzymes. Pre-cooking consists of exposing the whole or the de-headed prawns, shell-on or peeled, to water vapour or hot water long enough to heat the product to a temperature so that the surface protein of the prawns coagulates, but the protein in the centre is not coagulated. When the crustaceans are cooked, coagulation of the protein also occurs in the centre (FAO 1978). In some countries, depending on the species of shrimp or prawns, it is useful to pre-cook them to maintain the colour, to cause the tail to curl, to reduce crumbling during handling and to reduce the level of micro-organisms.

For some species of marine shrimp (e.g. *Pandalus* spp.), it has been found that the total period of cooking cannot exceed 3 or 4 min at 100°C if undesirable alterations in the texture and the unnecessary loss of weight are to be avoided. The thermal capacity of the source of heat needs to be adequate to bring the water to a boil 1 or 2 min after the prawns are added. The cooking period is measured starting from the moment that the crustaceans arrive at the foreseen temperature. Thus, prawn producers wishing to sell their product in a pre-cooked and frozen form should conduct experiments to produce the best quality and yield. The optimum cooking time and temperature, and the freezing procedures used to produce the best quality product are dependent on the quality of the original product, and the form and size of the prawns. After cooking, the prawns should be quickly cooled, using water or cold air, and packed according to the customer's specifications. It is important to avoid any contamination after cooking, since this product may be directly consumed without any additional cooking. However, pre-cooking and freezing is generally regarded as insufficient for consumption without additional cooking. Cooking is a critical procedure. It affects the texture, colour and flavour, and if done inadequately without proper experimentation to define the optimum time and temperature, the process can cause serious quality problems.

18.3.4 Industrial-scale freezing

Figure 18.7 provides a sketch of an industrial unit for the processing of cooked and frozen prawns. The sequence of operations and the equipment locations are correct, but the building dimensions will vary according to the dimensions of the equipment and the volume of prawns to be processed.

Normal prawn processing consists of the following procedures. When the prawns arrive at reception and will not be processed immediately, they are weighed, put into plastic boxes with ice and placed in cold storage to await processing. When the prawns are to be immediately processed, they should be washed, weighed, passed through a size grader, and transferred to the stainless steel processing table, where they are de-veined, de-headed, de-clawed, and shelled (as appropriate according to the desired product type). The prawns are then placed on another stainless steel table where they are prepared for freezing. If the freezing is done in a tunnel, layers of prawns, in bulk, separated by a

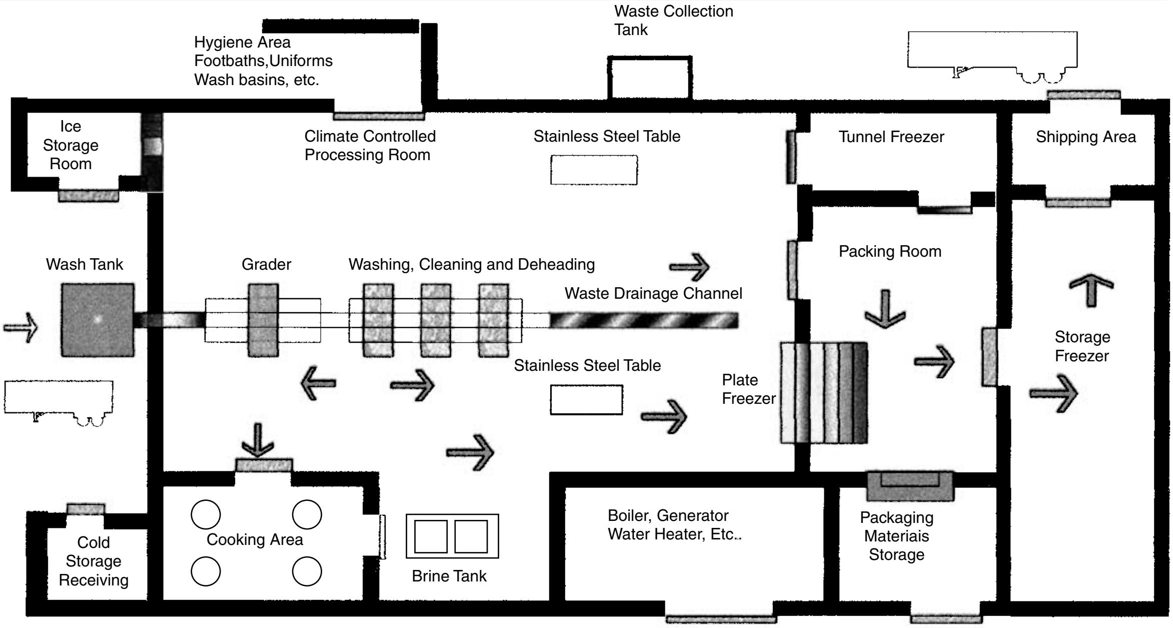

Fig. 18.7 Layout of processing unit for cooked and frozen prawns

plastic film, are placed in trays, and rapidly loaded on to trolleys for passing through the tunnel. The previously weighed prawns may be placed in bags or on trays. When the prawns are frozen in blocks, they should be placed, after weighing, in paraffin-waxed boxes or in aluminium compartments in block form. A large proportion of the prawns exported by Brazil are packed in 5 lb (2.27 kg) paraffin-waxed boxes with a plastic film liner and enough water added to cover the prawns before closing the box. This eliminates the need to glaze after freezing (however, glazing is always a superior technique). Freezing time will depend on the freezer type and on the thickness of the layers/blocks. The temperature reduction of the prawns to between –2°C and –5°C should not take more than 2 h. During this period of time, ice crystals are being formed in the internal and external part of the cells. The selection of freezers depends on the market that the producer wants to reach. After freezing, the prawns that have been put through the tunnel in bulk should be glazed, packed in bags, weighed, and packed in cardboard boxes of 20 kg. Prawns that have been placed in bags before freezing, in little trays or in paraffin-waxed boxes, are directly placed into the 20 kg cardboard boxes. After this stage, the prawns are stored in freezers at –18°C or below, awaiting shipment.

18.3.5 Effect of freezing

Vongsawasdi & Noomhorin (1996) compared *M. rosenbergii* that had been preserved by individual quick freezing, freeze drying, and canning. After 6 months of storage, three types of evaluation were carried out, namely instrumental, chemical and sensory. For individual quick freezing, instrumental and chemical parameters changed slightly during storage, while sensory evaluation indicated that the prawns were still appreciated by the panellists. For freeze drying, the prawns were given various citric acid treatments to preserve their natural colour and to suit the preference of the panel. The best treatment was found to be 0.2% citric acid for 25 min. Following storage, instrumental, chemical, and sensory evaluation had not deteriorated and showed similar quality to the IQF prawns. Sodium tripolyphosphate (STPP) treatment, at various levels, was used to improve texture, juiciness, and panel preference. Dipping in 7% STPP for 15 min was found to be the most satisfactory. Though few instrumental, chemical, or sensory changes were detected after 6 months storage, canned prawns, though accepted by the panellists, were judged inferior to either IQF or freeze dried prawns. Reporting what appears to be the same experimental work, Noomhorn & Vongsawasdi (1998) stated that the freeze dried and canned prawns were stored at 24°C, while the IQF prawns were stored at –25°C.

Repeated freezing and thawing of stored prawns will have a different effect on the shear force required to break prawn tails of cooked frozen animals as opposed to those of uncooked animals. Srinivasan *et al.* (1997) observed that the shear force required for cooked prawns decreased after three cycles of freezing and thawing, while the shear force for raw prawns remained the same after five cycles. Electrophoretic analysis revealed gradual decreases in myosin, actin and most other myofibrillar proteins during refreezing and thawing. Studying the effects of freezing and thawing procedures, Srinivasan *et al.* (1998) found that during a 6-month storage period, lipid oxidation in raw muscle tissue reached a maximum between 1 and 3 months, and then decreased thereafter. The kinetics of this process depended on the presence or absence of shell and the rate of thawing. During storage, the texture (shear force) of raw muscle decreased slightly (3.5–8.1%) but the shear force of cooked prawns increased considerably (13.0–27.9%). Cooking loss was greater for shell-off (20.2%) than for shell-on prawns (14.4%) and correlated with increased toughness of cooked muscle. Electrophoretic analysis showed no protein changes, except that the intensity of all protein bands decreased slightly after 6 months storage. Although lipid oxidation products were higher in prawns stored with intact shells, the lag period was longer when compared to shell-off prawns. In general, blast freezing produced slightly higher muscle shear forces than still freezing. Slow thawing (i.e. in a refrigerator) was also shown to result in higher shear forces than intermediate (water) and fast (microwave) thawing. Lipid oxidation was affected by the thawing rate and was the highest when prawns were stored in a refrigerator. The presence of shells did not protect the raw muscle tissue against lipid oxidation but reduced cooking loss. Oxygen exclusion (vacuum packaging and/or antioxidant and dip or spray treatments) would be desirable for preventing lipid oxidation during long-term frozen storage. In summary, the presence of shell is obviously beneficial for frozen-stored prawns as it reduces cooking loss and prevents texture deterioration. Thus, storing de-headed prawns with intact shells would be the preferred method of frozen storage, especially on a short-term basis.

Joseph *et al.* (1992) found that the quality of frozen prawns in blocks collected from cold stores in India, after approximately 2 months of storage, varied considerably. White spots on the shells often occur in frozen prawns, thus decreasing market acceptance, but were not caused by desiccation, as the blocks were well glazed. The freshness of the product at the time of freezing, as emphasised in section 18.3.3, was found to be more important and caused perceptible organoleptic differences. The exact cause of the white spot discoloration was not known.

18.4 Handling for live sales

Live sales present a different set of problems than the sales of chilled or frozen prawns. The techniques are similar to those used to sell live lobsters or finfish. The water needs to be changed regularly to eliminate ammonia build-up and the temperature needs to be held relatively constant. An air source is necessary to keep the oxygen levels of the water above 6 p.p.m. to lessen the risk of ammonia toxicity. The prawns to be transported live should be washed in non-chlorinated clean water. They then should be held at a temperature that can be maintained during transport. Thermal shock should be avoided. It is advisable to transport at about 22°C and to use small amounts of ice to keep the temperature constant, as needed. These transport techniques are similar to those used to transport prawn postlarvae from hatcheries to distant grow-out facilities by road transport (see Chapter 5). Generally, restaurants or seafood speciality sales outlets will have aquaria to display live products. They may also have larger tanks for storage. Live animals are of best quality if sold within 5 days.

18.5 Practical processing techniques

Processing is frequently carried out on-farm by relatively inexperienced people. Where most of the farmed *M. rosenbergii* is sold fresh and whole this does not result in too many problems. Prawns are usually harvested when the sun is not strong in the early morning, or at night, and immediately put in ice water to chill and kill the animals.

In the Costa Rican freshwater prawn farm, Langostinos Koko, which is close to the sea, prawns are put in an ice water bath consisting of chlorinated full-strength seawater and ice for 45 min. Since this process has been utilised, the farm has not had any problems with soft animals reaching the consumer. Previously, this was a frequent complaint. In this farm the product is then packed in plastic bags and stored on ice. The fresh product needs to have the ice drained regularly so that the product does not come into contact with the cold water. If it is to be sold fresh, it should be sold within 2 to 3 days, and if frozen, it should be frozen within 2 days. The product should not be stored under a great deal of weight because this accelerates the onset of 'mushiness'.

Freezing needs to be rapid and very cold. Storage of whole prawns at –30°C significantly retards the progress of 'mushiness' caused by the presence of the hepatopancreas. With this process, prawns can be held for up to 6 months at –20°C or lower. Care must be taken to ensure that the product is stored in rotation in the freezer. Newly frozen product should be put in the back of the storage facilities and the older product used first. Another important consideration is the method of handling frozen prawns after they leave the packing plant freezer. They need to be maintained frozen until use. These issues are further discussed in Chapter 19. Frozen product needs to be packaged in a way that facilitates the end user being able to defrost the amount needed on each single occasion, without having to refreeze any remaining product. Repeated freezing and defrosting can produce a 'mushy' product.

18.6 References

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19

Marketing and Preparation for Consumption

Harold Phillips and Denis Lacroix

Kennedy (1991) cautions against the classic entrepreneurial nature – 'Ready?, FIRE! Aim'. Marketing freshwater prawns effectively requires an understanding of the characteristics of the product, and the needs of the customers and potential customers. In most of the major producing countries (e.g. China, Vietnam, Thailand, Bangladesh) there is no inherent difficulty in marketing freshwater prawns. If the price is affordable for the local consumer, the product will 'sell itself', because it is an established commodity that is (or in some cases was) available from the capture fishery. Under these conditions, marketing can focus on value-addition; focus marketing may produce more revenue for the producer. If the export of freshwater prawns to the mainly temperate developed areas of the world – Europe, Japan, USA, for example – is to be increased, the product needs to be carefully marketed. The same applies if they are to be sold in tropical countries capable of rearing *Macrobrachium rosenbergii* where there is no traditional market for freshwater prawns. In countries where other species of *Macrobrachium* are familiar but the long-legged Malaysian giant prawn (*M. rosenbergii*) is not, similar marketing considerations would apply. Under these conditions, a good reputation for tastiness and quality will need to be established and maintained; if this is successful, sales will increase as more product becomes available.

To many new consumers, *M. rosenbergii*, once deheaded, looks like marine shrimp. However, it tastes milder and requires different handling, particularly if it is sold head-on. Marketing needs to convince its customers that this distinctiveness can be an asset. Some are already convinced about the attractions of freshwater prawns and require little conversion. The Brazilian writer Jorge Amado (1995) once wrote 'I am crazy about Pitu [the Brazilian name for most freshwater prawns]. Every time I remember the taste of these steamed prawns, my mouth begins to water. This fruit of the river is more savoury than any seafood – shrimp, spiny lobster, or crayfish. They have the taste of my bahianese youth.' However, even to such a fan of freshwater prawns, the first sight of *M. rosenbergii*, which has a different appearance to one's native species (being indigenous to lands far from home), may be a surprise. *Macrobrachium rosenbergii* is the main species that is reared globally, for technical reasons, but its introduction into markets where another species of *Macrobrachium* is well known may encounter the same type of resistance that was originally experienced when farmed Atlantic salmon were compared with those caught in the wild.

The emphasis of this chapter is therefore oriented mainly towards marketing freshwater prawns in areas where consumers are not totally familiar with the product. This is not so difficult in some countries as it used to be. For example, freshwater prawns are a common sight in supermarkets in the UK, where they were unknown 20 years ago (M. New, pers. comm. 1999).

19.1 Historical perspective

Specific experience on market research with freshwater prawns in several countries is presented in section 19.2, while a number of marketing case studies are presented in section 19.7. Early work on this topic was reviewed by New (1995); much of the information in this section has been extracted from that source to provide background material for the rest of this chapter.

Although there was originally considerable interest in freshwater prawn farming in the western hemisphere, technological developments enabling the explosive growth of marine shrimp culture for supply to an expanding global market pushed the former into the background. Markets for freshwater prawns were perceived as mainly domestic; now there is evidence that there is more scope for increasing the export of freshwater prawns, which is causing a new impetus in its aquaculture.

It is difficult to determine the quantities of freshwater prawns that are exported because export/import statistics frequently do not distinguish between marine shrimp and freshwater prawns. Similarly, farmed shrimp or prawns are often not distinguishable from wild-caught animals in such statistics. While morphological differences between prawns and shrimp are obvious when they are marketed head-on, and are visible to the more discerning consumer when tails are sold shell-on, head-off shell-off prawns and shrimp are indistinguishable to consumers in external appearance. However, labelling requirements in many countries are increasingly identifying the type and origin of all products. So far, there is little consumer demand to know which products are farmed and which are wild-caught (as there are in salmonids) but here again, this is changing due to labelling laws. There is also an increasing demand for products that are either caught or reared in a responsible, sustainable manner (Chapter 23). According to New (1995), freshwater prawns do not generally compete with marine shrimp. Indeed the markets in most countries where they are reared are quite distinct and, for many, the taste and texture of freshwater prawns is superior to that of marine shrimp.

Early attempts to market freshwater prawns in continental USA, which had been reared in Brazil, Hawaii, and the southern States of the USA, were reviewed by New (1990) and are dealt with in section 19.2.4 of this chapter. The problems of locally high production costs have been effectively demonstrated by experiences in some of the French Overseas Departments and Territories. By 1987, after the local market was satisfied, a farmers' cooperative in French Guiana started exporting head-on frozen *M. rosenbergii* to metropolitan France (Lacroix 1991). However, the market price required to ensure profitability was much higher than that charged for prawns from Southeast Asia. This experience is further related in section 19.2.1. Lack of regular supply, rather than poor demand or profitability, has been a major constraint in the marketing of farmed freshwater prawns in developed countries (New 1990).

In 1992, Bangladesh was described as a major exporter of *M. rosenbergii* caught by artisanal fishers in rivers, lakes and flooded depressions, thus stimulating the development of farming there (Angell 1992). Though it is still difficult to know what proportion of the freshwater prawns exported by this country are farmed, there is no doubt that Bangladesh is a major source of farmed product (see Chapter 17). More than a decade ago, freshwater prawns from Bangladesh were accepted in the Belgian market because they had a similar taste to the preferred coldwater *Crangon* spp. (Nierentz & Josepeit 1988). Italy and Spain have a strong tradition for (consuming) head-on shrimp (Griessinger *et al.* 1991) and generally increased living standards were said to be stimulating their consumption in the home, as opposed to restaurants, thus presenting a potential market for whole freshwater prawns.

Sadanandan *et al.* (1992) forecast a good potential for exports of freshwater prawns from India but thought that a specific brand image was desirable. Two exporters were already reported to be exporting *M. rosenbergii* under the name 'scampi', a generic name associated with other crustaceans in the developed world. The current situation for farmed freshwater prawns in India is discussed in Chapter 17.

In 1992, the USA market for freshwater prawns was described as being in transition (Chauvin 1992). There were two market niches: imported frozen tails, mainly from Bangladesh, Indonesia, Malaysia and Myanmar, and fresh (mostly head-on) from Costa Rica, Ecuador, the Dominican Republic, Mexico and, domestically, from Hawaii and Puerto Rico. Both *M. rosenbergii* and *M. carcinus* were marketed at that time. In the mid-1970s, when the import of freshwater prawns in the USA began to exceed 1000 t/yr, it was first thought of as a marine shrimp substitute. Sales had peaked in 1989 at 15 000 t but exact figures were unknown since US Customs authorities did not distinguish freshwater prawns from marine shrimp. Most imports were frozen tails from Asia. As imports of the marine shrimp *Penaeus monodon* began to escalate, imports of freshwater prawns by the USA declined (to an estimated 6000 t in 1991) but a greater proportion were of the larger-sized animals. The recession at that time was also said to be a factor in the decline. Most of the reduced Hawaiian production (see section 19.2.2) was being sold locally by that time, much of it at the farm gate. This was also occurring in Puerto Rico. In continental USA, marketing prawns from Puerto Rico or Texas was being promoted to high-class restaurants in Chicago and other major cities but this market niche was seen as quite distinct to that for Asian prawns (mainly wild-caught) and black tiger shrimp.

Chauvin (1992) forecast that the USA market for *M. rosenbergii* would continue towards the use of larger tails in the frozen market segment. A greater incidence of Food and Drugs Administration (FDA) rejections of Asian freshwater prawns on quality grounds, as opposed to black tiger shrimp, was noted at that time. A market niche for farmed freshwater prawns of consistently high quality was therefore identified. This niche remains open and this finding explains the necessity for emphasis on quality standards in handling and processing (Chapter 18) and in exploiting market opportunities through efficient marketing strategies, as noted in the current chapter.

19.2 Market research and developing a marketing plan

The goal of all producers should be to get the maximum net value for their products, in other words the maximum value, net of distribution and marketing costs, which can be obtained from the product. It is necessary to plan stocking dates, harvesting practices, etc., to produce a consistently high-quality product, to have the maximum product available to meet peak demand, and to develop the optimum market. Market research is one tool that can be used by producers to help determine the appropriate way to market *M. rosenbergii.* The results of some examples of market studies in various countries concerning freshwater prawns are provided below.

19.2.1 France

Freshwater prawn farming started in the French Overseas Territories in the early 1970s. French Polynesia was first, with breeders imported from Hawaii, then the twin islands of the Caribbean West Indies, Martinique and Guadeloupe, and finally, French Guiana, on the northern coast of Amazonia. In French Guiana, a long-term development plan had been established for agriculture, including aquaculture. The goal was to produce 500 t of *M. rosenbergii* for the international market. The main technical and biological problems had been progressively solved by the 1980s and production reached 70 t by 1987, much more than the local market could absorb. The producers' association understood that the export price was linked to the price of the traditional product from Southeast Asia (US$ 8–10/kg, whole) which was 40% below the French Guianese production cost. The farmers asked public authorities and IFREMER, (Institut Français de Recherche pour L'Exploitation de la Mer), formerly CNEXO, to undertake market research in order to assist them develop a marketing plan for the French Guianese situation.

A marketing consultancy, which specialised in the seafood trade and the department of economics of Ifremer, developed a study which showed that there was a 'niche' market in French supermarkets for the product if it was presented whole and fresh. This required dependable transportation from Cayenne to Paris (7500 km) twice a week. The French study was similar to the USA (see section 19.2.4). Its conclusions included the observation that the product needed to be presented as a new and exotic delicacy, that point-of-purchase materials with recipes and other information needed to be available, and that opportunities for free tasting should be offered. This very detailed programme was carried out during a 2-year promotion campaign with a few selected supermarkets (1988–1989). Unfortunately, this did not result in a successful future for French Guianese producers of *M. rosenbergii* and there has been a lull in production there, which only started to revive in the late 1990s (Chapter 17). A major lesson from this 12-year experience was that the target market needs to be considered from the beginning and that market analysis is the job of professionals, not of producers (Lacroix *et al.* 1994).

19.2.2 Hawaii

Freshwater prawns have been cultivated in Hawaii since 1965 (Lee 1985). Prior to 1973, most were sold through a local retail seafood market, Tamashiro Market. Interest was high but not sales. The market development required:

- a steady supply of prawns;
- a high-quality image through marketing live prawns; and
- a premium price for the live animals.

By 1971, Tamashiro Market had developed a small but consistent customer base. Slow increases in production had resulted in a consistent demand for the product. In 1978 a large farm began production. To encourage the development of the market for prawns, the Hawaii Prawn Promotion Program (H3P) was begun in 1982 (R. Fassler, pers. comm. 1998). H3P was a joint industry–government programme with the State of Hawaii appropriating funds for the project. The contracted advertising agency made the assumptions that:

- the primary local market was in restaurants (emphasis on the tourist trade);
- the product would be sold and presented in whole form;
- both frozen and fresh chilled product would be available but frozen would be emphasised;
- after 2 years large quantities of prawns would be exported to continental USA; and
- the product had a relatively high cost of production.

In the first year the emphasis was to be on the Hawaiian restaurants. The product was to be positioned as premium local seafood. In this textbook approach to marketing a new product the plan was to:

- create a generic product name (Hawaiian Prawns) and a logo;
- develop a brochure containing product information; and
- utilise media advertising and develop collateral materials to reinforce other tools.

A food consultant was hired to create recipes for the Hawaiian Prawns (R. Fassler, pers. comm. 1998), some of which have been included in section 19.8.2. Seminar presentations were made at the annual meetings of the Hawaii Restaurant Association and the Hawaii Food Industry Association. An exhibit at the 1980 Hawaii Hotel and Restaurant Expo included preparing sample dishes with the prawns. Although considerable publicity was generated by these events, few new customers were obtained because supplies of prawns were extremely limited. The success of the programme was undermined by poor product availability.

Due to the limited availability of product the emphasis was placed on the retail trade. The recipes and promotional materials were not in great demand. The customers were already familiar with the product and did not need the additional materials. This project was a great example of the 'Ready? FIRE! Aim' approach. It was a good generic marketing programme which the farmers were unable to supply product to support. Without adequate and relatively consistent product, marketing can be a waste of money. Insufficient supply of product also frustrates the consumer. Marketing *Macrobrachium* must be co-ordinated with product availability.

19.2.3 Puerto Rico

In Puerto Rico, numerous studies were conducted for the Sabana Grande freshwater prawn farm (49 ha in 1985), which verified both the market potential for the product and the problems associated with inappropriate handling (J. Glude, pers. comm. 1992). A series of basic guidelines were developed in response to this (Table 19.1). The result was that the farm believed that this species needed to be marketed as a new and unique product and not as a 'second-quality shrimp' just because it was coming from freshwater. For that purpose, in 1985, it hired a young marketing specialist from Harvard University to identify the strengths and weaknesses of this species and develop a realistic marketing programme, the 'Royal report' (D. Lacroix, pers. comm. 1999). Farms in the Caribbean and Latin America were visited during the study. Then, in close co-operation with the farm's owner, John Glude, whose experience with seafood marketing in general and with *M. rosenbergii* marketing in particular was invaluable, the consultant selected the key factors for the optimum marketing of the freshwater prawns (Table 19.2). This study also resulted in the observation that it was safer to begin by selling the product at a high price, even if distribution was more complicated and marketing more difficult. Price frequently establishes the quality image of the product.

All the elements of a marketing plan for local sales and for the mainland USA market were assembled by this farm, which continued to sell in Puerto Rico and the northeastern part of the USA until production problems and financial problems with its importer in the USA, caused the closure of the farm in 1993 (J. Glude, pers. comm. 1999).

Table 19.1 General recommendations for handling and storage of freshwater prawns. (Source: Sabana Grande farm, Puerto Rico; later used by Langostinos Koko, Costa Rica.)

Do's

- Fresh langostinos can be stored in your refrigerator, covered with ice, for up to 5 days after their arrival.
- The ice should be changed daily and while doing so, rinse the prawns with cold water.
- Place frozen langostinos in your freezer immediately on receipt.
- Keep the product at –20°C or below until ready to use.
- For the best results, cook and serve immediately after thawing or removing from ice.

Don'ts

- Don't thaw more langostinos than will be required for cooking.
- Don't re-freeze thawed prawns.
- Cooked prawns can be frozen but don't re-freeze thawed prawns.
- Don't thaw for more than 10 min.
- Don't leave prawns unprotected in the freezer; keep the container closed.
- Don't leave prawns at room temperature.

19.2.4 Continental USA

Market research to determine the acceptability of various presentations of *M. rosenbergii* has been somewhat limited. In 1982, the Aquaculture Department of the State of Hawaii authorised a market research study to determine the feasibility of retail sales of the freshwater prawn in continental USA, (R. Fassler, pers. comm. 1998) which revealed problems related to the lack of experience of the consumer with the product. Production problems in Hawaii made the possibility of actually marketing in continental USA a moot point, but the potential problems were associated with consumer acceptance of the head-on prawn, the 'mushiness' problem (see Chapter 18), and handling and preparation techniques. It was determined that mass merchandising of the product would require a considerable investment in promotion and advertising, to educate the consumer.

In the later 1970s, during a seminar on *M. rosenbergii* in the western hemisphere, various marketing problems were identified (Hanson & Goodwin 1977). The public in the USA was noted as having conservative tastes in foods; some unique skills would be required to introduce a new freshwater head-on crustacean to the USA market. This assessment seemed to ignore the niche marketing that has

Table 19.2 Main consumer concerns with *Macrobrachium rosenbergii* in the USA and their rebuttal.

Consumer concerns	Specific marketing response
• 'It is not a genuine shrimp'	• Give it an attractive commercial name
• 'Where is it from ?'	• Find an origin which adds value: tropical, holiday style, outdoor cooking, etc. • Explain it is not a well-known shrimp because it is 'rare' and 'new'
• 'The quality is uncertain'	• Aquaculture provides reliability in freshness, taste, size grade, origin, and process control
• 'It is tasteless'	• It is not flavourless, it is 'sweet' • It is a 'diet shrimp' as the cholesterol ratio is lower than in marine shrimp • This subtle taste facilitates numerous recipes with very different sauces and styles, which is an advantage for all chefs
• 'It has a big head'	• Market it whole • Fresh presentation is more attractive for the consumer than cooked

been done so successfully with many specialised seafoods. It focused on the typical housewife as the consumer for the product. In the conclusion this seminar identified the most critical element in the marketing concept as product positioning. Identifying the product with a common name was a key issue. A recommendation was made to use a brand name (e.g. 'Malaysian Prawns', 'Hawaiian Prawns', 'Caribe King Prawns', etc.) and to identify the product as freshwater shrimp.

Prior to investing in farms for cultivating the freshwater prawns, Red Lobster Restaurants conducted in-house studies which determined, to their satisfaction, that the prawns were very acceptable to their customers. They tested prawns cooked in various ways at different restaurants and found the product was very desirable when properly prepared.

Liao & Smith (1984) summarised a study on marketing prawns in South Carolina. All retailers who participated in the study indicated that the prawns were highly saleable and that they would market the product if it were available. Half of the retailers preferred the product as fresh head-off, while the other half indicated that whole fresh prawns and frozen prawns were acceptable. Some 75% of the retailers marketed the frozen prawn tails with no difficulty but the two retailers who marketed the whole prawns indicated that the product was more difficult to sell. The retailers indicated a preference for a graded product. Retail prices were comparable to marine shrimp during the product sale period. Half of the seafood retailers were willing to pay the same price for the prawns as for the same size of marine shrimp, 25% were willing to pay more and 25% would pay 10% less. Head-on prawns would require more effort to sell but a definite market for this product was identified.

Further comments on early attempts to market freshwater prawns in continental USA are contained in a paper by Rhodes (1985).

19.2.5 Other countries

In the early 1980s the small sizes from harvests in Taiwan were sold at a relatively satisfactory price, almost equal to the larger sizes and much less expensive to produce. Feed conversion ratios (FCR) were found to be better for the smaller-sized animals. Fuelled by the domestic demand for small freshwater prawns, increased stocking densities led to greater productivity per unit area. However, highly intensive cultivation probably contributed to the water quality and disease problems that produced the rapid decline which occurred in Taiwanese production, and this marketing strategy is not to be recommended. Many other countries have a tradition of freshwater prawn consumption. Marketing in these areas presents few real problems. The product has always been well accepted and marketing in areas such as the Indian subcontinent, Southeast Asia, etc., will therefore not be detailed here. The existence of a capture fisheries for the species vastly simplifies the marketing of the cultivated *M. rosenbergii*.

Care should be taken about the true origin of freshwater prawns. For example, Thailand imports prawns from Bangladesh, Myanmar, and Vietnam, for processing and re-export (S. Thongrod, pers. comm. 1999). In such cases, the reputation of the exporter is the most important factor in selecting the prawns.

19.3 Marketing live or fresh prawns

Marketing live or fresh product is defined by its ability to survive during transport and display, and its shelf life. A large proportion may be pre-sold before it is harvested. It needs to be moved rapidly to the ultimate consumer for acceptable quality to be maintained. If non-live product is to be held for any length of time, it should be frozen.

19.3.1 Marketing live prawns

D'Abramo *et al.* (1995) stated that adult freshwater prawns can be successfully transported live for at least 24 h at a density of 600 g/L, with little mortality and no observed effect on the exterior quality of the product. Transport under these conditions requires good aeration. Distribution of prawns on 'shelves' stacked vertically within the water column helps to avoid mortalities caused by crowding and localised deterioration in water quality. Holding animals in water with a comparatively cool temperature (20–22°C) minimises incidences of water quality problems, as well as the injuries caused by encounters, by reducing the activity level of the prawns. Live animals can be transported densely if they have sufficient oxygen. Prawns will normally survive fairly well for a week densely packed in restaurant aquaria with a functioning biofilter.

In Thailand a large percentage of the cultivated freshwater prawns are sold as live animals to restaurants that display the product in aquaria and sell from them. These live animals bring a premium price which justifies the higher handling costs. Farmers in Thailand auction the live product to truckers at a central farm. The truckers deliver the live product to seafood restaurants in centres of population, using small pickups with tanks and aeration devices to keep the product alive during transport. Farmers also sell fresh product (not alive) at a price significantly lower than the price for live animals to the same truckers. Thai farmers might improve their net profit by developing a marketing co-operative and controlling the distribution directly but it is possible that the additional investment and effort might better be used to expand production. There is a significant risk associated with losing control of distribution, but the costs associated with gaining control of the market are significant. In Thailand the product is well accepted and the channels of distribution are well established.

In other markets the problems are different. Fishing ponds are popular in Taiwan where customers fish for their own prawns. This seems to be a very profitable enterprise. The captured prawns are weighed and the prawn fishermen pay according to the weight of the captured prawns that they take home, or cook on the premises in outdoor barbecues. According to Liao & Lu (1995), the sale of live prawns to urban fee-fishing operations is one of the major marketing outlets for prawns in Taiwan. Although Chien (1992) noted that freshwater prawn prices more than doubled between 1983 and 1984, due to the popularity of recreational fishing (angling) for prawns in urban areas, his analysis suggested that the expansion of prawn farming in Taiwan could not be based upon the live market segment for fee-fishing prawns. In contrast, Lo & Hwang (1994) recommended that Taiwan's industry consider 'value-added leisure' marketing niches such as fee-based recreational fishing services.

Freshwater prawns are very active and make an interesting feature in an aquarium. The main problems are their tendency to eat expensive fish and that other fish will eat the prawns especially just after a moult. The prawns are exotic in appearance and have a reasonable life span in aquaria. In California they are marketed by Blue Lobster Farms, as well as a number of aquarium shops. Prawns can also be used as bait. They are very active and attract many types of fish. Some fishermen will pay a large premium, up to twice what they will sell for as food, for live active freshwater prawns; they are very effective in freshwater, brackishwater and seawater fishing. If the farm cultivating freshwater prawns is near popular fishing areas, selling some freshwater prawns for bait may be a very attractive option. Postlarvae (PL) may also be sold to hobbyists and schools. In Florida PL were being sold for up to US$ 100/1000 in 1999 in limited quantities. Quantities above 10 000 were being sold for US$ 50 to 60/1000 (B. Patterson, pers. comm. 1999). However, such activities should be practised with caution. Their use for bait is only advisable where *M. rosenbergii* is indigenous, in order to avoid the introduction of an exotic species in natural waters.

19.3.2 Marketing at the farm gate

Farm-gate marketing occurs in Brazil but it is not very common. However, prawns are frequently offered along the roadsides. Some farms, which are near to tourist or commercial routes, take advantage of these strategic sites to sell whole prawns (fresh or frozen). A large farm near an important tourist beach in the Amazon region sells almost all of its production at roadside sites during holiday periods (P. Moraes-Riodades, pers. comm. 1999). Many small farmers market prawns directly to friends, colleagues and relatives; in addition prawns are often delivered to customers' homes or work places. Comments on the farm-gate marketing of freshwater prawns in Brazil are contained in section 19.7.1.

In Costa Rica the sole freshwater prawn farm is situated on a road leading to the major beach resorts in the area. Fresh product is offered at prices slightly higher than the wholesale delivered prices. Frozen product is available if all of the freshwater prawns are not sold within the first 2 days after harvest. The frozen product is not allowed to get more than 2 weeks old before it is sold. Live product and processed product are available only by special advance order. Billboard-type signs on the road announce the availability of freshwater prawns. Contacts are made with local restaurants, bars and hotels offering recipes and special promotions of the product. The farm's roadside stand stays open 7 days a week when product is available.

Other lessons can be learned from the experience of selling prawns live in Costa Rica. Other products, such as Dorado (Mahi mahi) and tilapia, are purchased for resale, in order to make the farm's roadside stand more useful to the customers. When they are available, ornamental fish are also sold. Sales at the roadside stand are the most profitable sales and most are for cash. Point-of-purchase promotions include price signs, instructions on how to take care of the product and recipe flyers with three to five recipes showing interesting ways to prepare freshwater prawns (included in section 19.8.2). Banners and flags can be important ways to attract more traffic to farm-gate sales points. Flags and pennants that are fresh and clean attract attention and get people looking at the product. Balloons have also been found helpful; they are inexpensive and can be very effective. Sales to employees are a special situation. The price needs to be attractive to discourage theft and for them to feel that they are receiving a special deal, but not so attractive as to encourage resale activity on the part of the employees. Pricing is designed to remain relatively stable. The retail sales price (1999) of 'jumbos' (6–12/kg) is approximately US$ 10/kg; other sizes are cheaper. Prices are adjusted every 4 months to keep them in line with marine shrimp prices. During times when marine shrimp are very expensive, freshwater prawns are slightly cheaper than marine shrimp.

Several farms in the French West Indies offer tourists the opportunity to buy freshwater prawns and to visit the farms and test Caribbean traditional recipes in a restaurant located close by. One example is 'Habitation Lagrange', near the 10 ha farm of Seguineau, on the Atlantic coast of Martinique, along the main tour road of the island. Several small farms supply traditional restaurants built in the hills. Customers are invited to go to the farm to see the ponds and to buy prawns at a 'wholesale price', in the same way as rum is sold in traditional distilleries. Similar marketing activities are conducted in Guadeloupe. This technique is linked with a general trend to add value to all traditional and typical products of the island: handicrafts, rum, flowers, etc.

In Hawaii many farms sell a large percentage of their prawns at the farm gate as a fresh product. Regular harvests have allowed farmers to offer fresh product at the farm gate since the 1970s. For example, Amorient, the biggest shrimp and prawn farm in 1982 (45 ha, one-third used for *Macrobrachium* production) offered tourists a 'visit and taste' break during their round-trip bus tours from Honolulu. Tourist groups were driven to ponds where they could take pictures of manual harvesting. Next they went to a 'tasting hall' where they could purchase plastic ramekins (a small Japanese-style plastic disposable tray) full of freshly boiled tails with different sauces. The tasting hall displayed aquaria with live shrimp and prawns of different sizes and posters on the ecology and the biology of these species. Caps and T-shirts with the farm logo and various types of shrimp and prawn drawings were available at the gift store. The excellent location of the farm, near the northern highway to the surfing beaches, the interest of people in the new and exotic activity (aquaculture) and the good management of the bus visits resulted in the sale of the entire production at a very profitable price, US$ 4.4/kg above the marine shrimp price (US$ 19.8/kg). Farm-gate marketing is a function of local conditions. Some Hawaiian farms set up a specific day every week that farm-raised prawns will be available. Many people drive considerable distances to purchase prawns. The roadside signs are modest, basically saying, for example, 'fresh shrimp available Tuesday and Friday 8:00 to 10:00 A.M.'. These roads have substantial traffic. Sometimes calls are made to customers that have registered with the company to notify them of prawn availability.

The Sabana Grande farm in Puerto Rico sold directly to tourists and locals. A signpost with a great logo and the brand name 'Langostinos del Caribe' helped drivers to reach the farm from the southern highway. Caps, T-shirts, and prawns in various sizes and packaging were available. In 1988, sales at the farm-gate represented about 30% of total sales and were very profitable. Most of the rest of the domestic sales went to major local hotels and restaurants.

Seven farmers who participated in prawn farming trials in 1981 in South Carolina sold a sig-

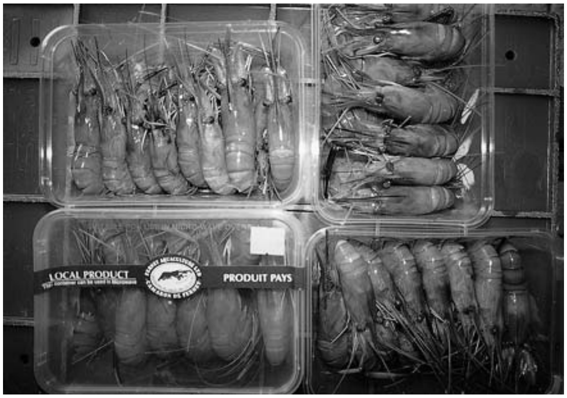

Fig. 19.1 Freshwater prawns packed by Ferney Aquaculture, Mauritius. (Source: Yann von Arnim.)

nificant portion of their product with a small newspaper advertisement stating that fresh prawns would be available at harvest time (Liao & Smith 1983). The majority of consumers rated the product excellent in taste, texture and ease of preparation. Some 88% said they would buy it again. Most expressed a preference for the head-off fresh product. The summary of the study indicated a very good market for the product.

It is very important that any sales facility marketing freshwater prawns should support the image of the product. It must be clean and attractive and the personnel involved should be clean and attired appropriately. It is very important that the product should be displayed correctly, be fresh or frozen properly, and be packaged to support the image (Fig. 19.1). Personnel need to be well trained and to know how to prepare the product and care for it; they also should be courteous and professional. Signs can be simple, but should be neat and supportive of the general image of cleanliness and freshness.

19.3.3 Marketing fresh prawns

In several Caribbean islands there is a confusion of names between the indigenous species (*Macrobrachium carcinus*) and the imported *M. rosenbergii*. The former is known as a delicacy in traditional Caribbean cooking; the numerous names come from old 'creole' terms, such as 'Cribiche', 'Z'habitants' or 'Ouassous' (king of the springs). Over-fishing and river pollution have made them scarce. When *M. rosenbergii* was introduced in the mid-1970s in the Caribbean, all retailers and restaurant managers used the reputation and the name of the genuine Caribbean prawns to sell its cultured 'cousin' at the same high price. Today, although increasing quantities of prawns are imported from Southeast Asia to meet local and tourist demands, the ancient and positive image of the Caribbean species facilitates the sales of fresh *M. rosenbergii* produced locally. The freshness and the ambiguity between the two species result in a high demand for the cultured 'genuine' product. It is actually a guarantee of quality, which justifies the higher price and secures local producers a marketing advantage over imported competition.

In Brazil, some small farms send whole fresh prawns, transported on ice, to retail outlets and restaurants, as well as directly to consumers (Valenti 1996). In Costa Rica, fresh product is sold to restaurants, hotels and supermarkets; much of it is sold at the farm gate (about 35%), while the rest is sold in the capital city (San José) or to beach resort restaurants and hotels. In San José, supermarkets purchase 40% of the product and the rest is sold to restaurants. As in Puerto Rico, trucks are used to deliver fresh product to restaurants, supermarkets and seafood retailers in Costa Rica. Frequently, the supermarkets repackage the product in shrink-wrap containers; in other cases they sell the product fresh by weight. Sometimes they freeze the product for future sales as a fresh or frozen product.

Consumer preference can be very location-specific and sometimes unexpected. While preferences for 'head-on' or 'head-off' prawns are commonplace, Egyptian consumers are said to prefer, unusually, 'claw-off' freshwater prawns (Sadek & Moreau (1996).

A programme was developed to produce *M. rosenbergii* in El Salvador (S. Malecha, pers. comm. 1992). The product was branded and shipped to the USA for marketing as frozen product. Almost all of the production, however, ended up being sold fresh for consumption in El Salvador. Currently there is only artisanal production of prawns in El Salvador. At one time Guatemala, Honduras and Panama all had commercial farms producing *M. rosenbergii*.

Currently production is very limited (see Chapters 1 and 17) and most is sold fresh.

In Puerto Rico, the main farm exported an average of 50% of its production to several continental American cities through Federal Express or United Parcel Service, though the local *versus* the continental USA proportion was very variable. Half of these exports (fresh) were for New York where specialised restaurants are numerous. The other half was dispatched to a dozen other cities along the eastern and the southern coasts of the USA.

In 1992 *M. rosenbergii*, once Hawaii's most popular species, was said to have enjoyed a comeback over the previous 2 years (R. Fassler, pers. comm. 1998). This was due to an improvement in production and to a dramatic rise in the whole animal price to US$ 15.45 to 19.85/kg. Most of the product is sold to the State's rapidly expanding Southeast Asian population.

In addition to sales of live animals, which fetch the best price, *M. rosenbergii* is also sold fresh and whole in restaurants and seafood markets throughout Thailand.

19.4 Marketing frozen prawns

Prawn tails which are frozen in ice blocks may be stored for over a year and still be very satisfactory, although 6 months would be more advisable. Frozen whole prawns can also be stored for long periods of time but they must be frozen and held at very low temperatures to retard the enzymatic action of the hepatopancreas (J. Glude, pers. comm. 1992). As stated in Chapter 18, whole frozen freshwater prawns will turn 'mushy' if they are thawed and re-frozen or if they are frozen and held above –20°C. This is a critically important consideration, since thawing and re-freezing is commonplace with the marine shrimp tails used in restaurants, despite it being bad practice! Freshwater prawns have a subtle and distinctive flavour. This topic is also addressed in Chapter 18.

In Brazil, frozen prawns are sold to supermarkets, retailers, restaurants, hotels and along the roads. Brazilian farms mainly market whole prawns (Valenti 1995). Frozen tails or peeled prawns are scarce. Big farms freeze prawns at –35°C and sell them to big supermarkets. However, several small farms freeze prawns using domestic freezers at –18°C and the result is a poor-quality product.

In Costa Rica the product is frozen for very short periods before sale. Very seldom does the packing operation have frozen product in storage for more than 2 weeks. The product is chilled, as in Puerto Rico (see below), sorted and packed into 1 kg plastic bags and then frozen. It is not glazed or vacuum packed; both of these techniques were found to significantly prolong the useful life of the frozen product but, due to the rapid consumption of the frozen product, there did not seem to be any need for this extra process.

The Sabana Grande farm in Puerto Rico prepared a list of basic guidelines for purchasers of *M. rosenbergii* (Table 19.1). About 60% of their product was sold frozen. Almost all product problems were traceable to mishandling. Once the consumers understood the requirements, they became loyal customers. Sabana Grande experimented with various forms of packaging including the traditional 5 lb (2.2 kg) prawn boxes. The farm chilled the product, sorted it, and then rapidly froze it in an ice-cream hardening freezer which froze at –35°C. Frozen at this level and maintained at a very cold temperature, the product was quite acceptable after 12 months of storage. However, where freezing facilities are less efficient (freeze more slowly) 6 months' storage would be more advisable. In Puerto Rico, the prawns were glazed with a very thin mixture of syrup and water, to prevent oxidation. Block freezing accomplishes the same goal but, when the product is shipped, the ice adds a great deal of weight.

Heads-off freshwater prawns have been sold in continental USA for some time. Chauvin & Rhodes (1982) discussed the marketing of frozen freshwater prawn tails from Bangladesh and Myanmar. Quality issues plagued this product. Mishandling or freezing at an insufficiently low temperature produced a reputation for this product as being 'mushy' and undesirable, a factor which has, until recently, hindered the effective marketing of frozen farmed freshwater prawns in the USA. In 1982, several New York importers ceased purchasing freshwater prawns because of inconsistent quality and past problems with FDA rejections. In general, at that time, the market channel members regarded the imported headless prawn as an inferior substitute for penaeid (marine) shrimp. In 1978 the prawns from Bangladesh were sold in California as tails, as an inexpensive substitute for marine shrimp. In 1998 Thailand began block freezing cultured de-headed *Macrobrachium*. They then shipped the prawns to a processor in Mississippi who defrosted the product, individually quick-froze (IQF) them and sold them to institutions and supermarkets. Block frozen tails from Thailand were once all exported to Japan but now Thai exporters are developing other markets and the product is of a very high quality, according to the Albertson's Supermarket chain (H. Phillips, pers. comm. 1998). In 1998 this USA chain bought about US$ 5 million retail value of this product; sometimes the product was in short supply. Its retail price (November 1998) was US$ 24.2/kg. No significant quality problems were encountered with this product.

The domestic market in Thailand for frozen *Macrobrachium* does not seem to be significant; most of the non-live product is sold on ice in supermarkets and in roadside sales (M. New, pers. comm. 1999).

In Toronto, Canada, whole *M. rosenbergii* were being sold in Kensington market in August 1999 under the name 'Tiger Shrimp' for CAN$ 24.0/kg. They had been defrosted prior to display.

Shell-on freshwater prawn tails are commonly seen in UK supermarkets; these are normally marked 'previously frozen'. At least in one UK supermarket (M. New, pers. comm. 1999) freshwater prawns are sometimes marked 'reduced'. The 'reduced' price is lower than for similar-sized marine shrimp tails, whereas the 'original' price was higher. While this makes freshwater prawns a bargain for the discerning consumer, it could hardly be a more effective deterrent for others, because it (falsely) implies some undefined inferior quality.

Farm-gate and retail prices for freshwater prawns in a number of other countries in 1999 are provided in Chapter 17.

19.5 Developing a marketing strategy for freshwater prawns

Kennedy (1991) defines marketing as getting the right message to the right people via the right media and methods. In the chapter on processing in this book, the strengths and weaknesses of *M. rosenbergii* were outlined. The right message means an appropriate message for the product and the targeted consumer. Marketing strategies for *Macrobrachium* need to be tailored to the specific situation of the selling entity and the potential buyers. As with any marketing strategy, the seller needs to determine the potential market for the various forms of the product and the profitability of delivering to that market. For example, if the volume of product produced is large but inconsistent and the market is also very large, frozen product may be the best way to plan to market it.

As with most products, it can be advantageous to establish a reputation for a high-quality product and begin the higher volume marketing later. If a product is introduced with a very high price and very high quality, it is simple to reduce the price and sell more of the high-quality product. On the other hand, if the product is sold cheaply with little regard for image and quality, it is very difficult to raise the quality image. If a farm starts by marketing fresh and live product to sophisticated buyers, who use the product correctly to produce very high-quality dishes at seafood restaurants with high-quality images, the product will very probably be well accepted when it is time to begin merchandising to a larger audience.

Market research has been used to try to find the reaction to *M. rosenbergii* (see section 19.2). One study in 1984 (H. Phillips, pers. comm. 1999) reported that the Hawaiian public needed extensive education to become mass consumers of freshwater prawns. This study missed the point that only a very small percentage of total consumers were required to purchase all the prawns that could reasonably be produced in that location.

Niche marketing seems to be appropriate for this product. Liao & Smith (1983) found that 50% of the retailers involved in a study in South Carolina indicated that sales of whole prawns would be acceptable. Restaurants said they would purchase whatever fresh product was available and two out of three restaurants found the frozen prawns acceptable. Some of the farmers participating in the study sold the product directly to the consumer as fresh or frozen tails. The conclusions were that there was a high acceptability of cultured prawns by seafood retailers, restaurants, and buyers in direct sales markets in South Carolina. The fact that prawns were not always available did not appear to be a major problem.

A significant part of developing a market strategy would be to identify and locate customers with a high probability for purchasing at an appropriate price. For *Macrobrachium* it might be the following:

- upscale seafood restaurants;
- seafood markets;
- ethnic restaurants that use whole prawns in dishes such as Spanish paella, French bouillabaisse, and many Thai dishes; and
- ethnic markets that target groups of people who frequently buy premium-quality seafood such as Japanese, Chinese, Cajuns, Portuguese, etc.

It is relevant to consider the personal experience of one of the authors of this chapter, in Costa Rica, which is detailed in sections 19.5.1 and 19.5.2. The major problem that marketing must address for *M. rosenbergii* is the handling and use of the product by customers and distribution channels. Most customers do not really know how to maintain the product in good condition.

19.5.1 Marketing strategies directed at restaurants and retail outlets

Chefs who are familiar with frozen marine shrimp tails think that the freshwater prawn product can be handled in the same fashion. Despite the fact that no responsible vendor would recommend freezing and thawing and re-freezing numerous times before use, this is a common practice with marine shrimp tails. When this technique is used with *Macrobrachium*, particularly with whole animals, the product turns 'mushy' and tasteless (see Chapter 18). A major marketing goal is to convince chefs to use and handle the product correctly. In many cases this is extremely difficult. Experienced seafood chefs are not inclined to listen to sales people.

In Costa Rica it was found that if the product requirements were directly addressed, chefs were warned about the potential problems, and demonstrations of the correct way to handle the product were provided, only about 10% of the chefs would follow these suggestions. However, on follow-up calls, when the chefs would tell farm staff how 'mushy' and unsatisfactory the product was, it was possible to begin to show them how to handle the product. Unsatisfactory product was always replaced and the problem explained to the chefs and other people working with the product. Without this sustained effort, the product would be purchased only when marine shrimp were not available, and the chefs would always complain. After working with the chefs with patience, persistence, and a careful understanding of their problems, however, these same chefs became excellent salespeople who convinced other chefs to use the product. Any chef in a major restaurant has a very difficult and complicated job, so working with them is both necessary, rewarding and frustrating. If a sales effort ends up convincing half of the chefs to follow the proper procedures, it is very successful. These chefs are then excellent customers. It usually takes several months for them to become fully convinced.

To deliver this message takes well-trained sales representatives who need to be fully informed as to the benefits and requirements for satisfactory use of the product. The philosophy of the product needs to be clear. The most effective sales presentations can be the testimonials of satisfied customers. The satisfied customer is also a repeat customer. It is impossible to over-use testimonials. It is necessary for trained sales representatives to contact the customer after the first sale to make certain they are satisfied. If the customer is not satisfied, then the representative can help deal with the problem. Their other important role is to keep the customers informed about product availability. When product is scarce, the customer needs to be kept fully informed.

Another effective sales promotion is to use chefs' schools, cooking schools and TV cooking programmes to promote the product. They are often looking for something novel and distinctive to help make their programmes more interesting. This technique provides an effective support for long-range sales. Sponsoring cooking contests for professional chefs is one way of recognising chefs and getting them involved with *M. rosenbergii*.

Retail sales outlets need to be supported. In supermarkets, point-of-purchase materials need to be made available for the stores to use. It is a good idea to have the materials in all appropriate languages. Point-of-purchase materials, for example, are mentioned in section 19.6. Frequently, in-store cooking demonstrations help a supermarket sell the product for years to come.

19.5.2 General marketing advice

Various presentation leaflets were developed in Costa Rica in the 1990s which were given to chefs and purchasing managers in supermarkets. These emphasised that the product is a gourmet, cultured prawn very different from any shrimp on the market today. Customers were told that it is grown in a pure freshwater environment, which gives it a delicate taste and tender consistency unmatched by the briny flavour and tough texture of marine shrimp. With its brilliant blue and slender claws, this new exotic species not only looks unique but its taste is unforgettable. Serving *M. rosenbergii* is in accordance with the trend to healthier dining – more seafood than meat, fewer calories, lower sodium and cholesterol. The leaflets urged that adding this delicious new seafood speciality to your home or restaurant menu is the best way to make it distinctive and to increase profits. A collection of promotional literature from various countries is shown in Fig. 19.2.

It is very important that sales representatives are honest with customers. Frequently, fish (and other!) sales people have a reputation for not being completely honest. If the sales representatives for freshwater prawns maintain a strict regime of honesty in regard to weights, prices, and product availability, and take responsibility for problems, it enhances the reputation of the product and helps to develop a solid customer base. In marketing, it is always worth using the fact that many of the most prestigious restaurants and hotels use the product. These examples of loyalty lend the needed credibility to the product and allow direct contact with new chefs. Promotional material for chefs may include references from other chefs, a list of clients, the guidelines information sheet (Table 19.1) and recipes using whole freshwater prawns (see section 19.8.2).

If the economics justify establishing a brand name, this is a way of protecting the quality image of the product. It may even be sensible to establish two brand names if the product is used in both retail and catering outlets, because chefs like to be able to purchase something the ordinary consumer cannot buy. If the product is sold whole, it can be packaged in a simple plastic bag, in a clean white box, or some other clean looking attractive container. When competition exists, the branded product has a decided advantage. When at all possible a label should be delivered with the product to ensure that as many people as possible have a telephone number from where they can order the product. Cooks and chefs frequently move jobs.

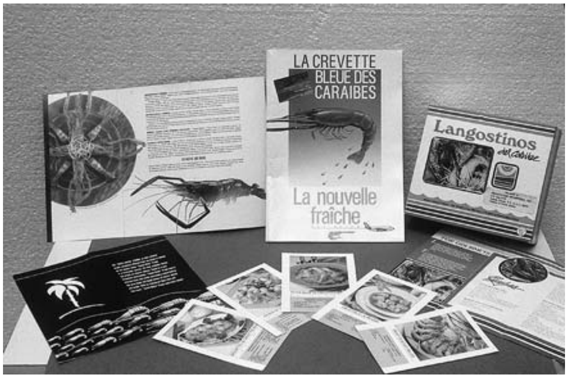

Fig. 19.2 A collection of marketing literature from France, the Philippines, Puerto Rico, and the USA. (Source: Denis Lacroix.)

19.6 Developing marketing plans

The marketing plan needs to be developed as a part of the overall business plan. Key elements include the identification of potential customers and their estimated consumption. Next, the production available to meet the demand needs to be estimated. Then the moment when various customers should begin to be contacted should be determined. It will take some time for the buying relationships to be established but it is counter-productive to begin marketing before product is available on a fairly consistent basis. Timing production so that product is available to meet demand peaks will help launch the product, especially if there is a shortage of other seafood. Marketing *Macrobrachium* is much more costly than marketing marine shrimp, where a commodity situation usually exists. The business plan must include adequate funds for this marketing effort and a clear definition of who will sell, who will buy, and who will distribute the product.

When only a small amount of production is available, it should first be sold to customers who are willing to pay a high price for a small amount of fresh product, for example white tablecloth restaurants, not supermarkets. Identify the marketer to be used for this initial marketing effort. Frequently, the farm owner can visit the restaurant and become a customer, thus providing the opportunity to know the owner of the restaurant; often he is also the chef and a very productive relationship can be developed for the restaurant and for the farm. Clearly identify the needs of the product and its limitations as well as its strengths. Virtually all successful chefs have close friends who are also chefs; they will use the products recommended by their peers. Branding becomes very important when such a close relationship is established. When the farm is invited to sell product to another chef, however, do not ignore the training phase. The new customer will not know what the old customer does.

Potential client lists can originate from the supermarkets, seafood markets and restaurants listed in the 'Yellow Pages', published lists of fine restaurants, restaurant guides, etc. Each consumer requires a different approach. Sometimes it is easier to use established seafood distributors to sell to these outlets. The advantage of using these is that they already have the contacts for selling the product and may have credibility with the customers. The disadvantage is that they may find it easier to sell other products and not provide the needed level of information about *M. rosenbergii* that is necessary to ensure repeat sales. If established distributors are used, they must be very carefully selected to ensure the type of representation needed. To achieve this level of representation the distributor will need to be highly motivated (i.e. it will cost money, either in terms of direct payment or higher commissions). It may be advisable to pay a special commission on the third sale to the same new customer; this encourages follow-up.

If in-house sale representation is to be used, the sales people must be carefully selected and trained. Initial contacts with major clients, such as supermarket chains, etc., can often be handled by the owners of small farms. One of the most rapid ways may be to talk directly to the head of the seafood counter at the largest market in the chain. This person will provide the information about who needs to be contacted to purchase the product for the chain, or he may be able to purchase independently. In all cases they need to be fully informed as to the product requirements. They also need to be supported with point-of-purchase materials (such as the guidelines shown in Table 19.1 and the recipes given in section 19.8.2). Training in-house sales representatives includes taking them on sales calls, helping them establish a prospect list, and teaching them how to handle and cook the product so that they can answer questions regarding the product.

Lee (1985), describing a successful promotion campaign for freshwater prawns in Hawaii, concluded that after the promotion:

- product recognition was good (85%);
- consumers and non-consumers both had a good image of the product;
- less than a quarter of the people interviewed remembered seeing advertising;
- a small percentage of the population were consuming most of the prawns; and
- prices and the whole prawn were perceived as problems.

A good marketing plan needs to be constantly updated as new situations are encountered. In every case, consistency of product quality and regularity of supply are the paramount factors in ensuring successful marketing.

19.7 Marketing case studies

Successful marketing programmes for any product involve recognising a significant benefit for the customer. In the case of *M. rosenbergii*, the product is excellent when used appropriately. It is easy to sell if the strength of the product can be properly demonstrated and its limitations clearly identified for the customer. A number of case studies are described in this section.

19.7.1 Brazil

Since *Macrobrachium* farming started in Brazil, producers have been selling their products in various ways, with different sizes, prices, and even names, such as 'Camarão da Malasia', 'Camarão Gigante', 'Camarão de água doce', 'Camarão do Havai', 'Camarão Pitu', and 'Pitu'. Prawns were often not killed in ice and were commonly frozen using domestic freezers, resulting in a poor-quality product. No recommendations were given to consumers, either about handling or cooking. Most consumers were confused and bought freshwater prawns thinking that they were marine shrimp. The lack of information, the unacceptable quality of the product, and the disappointment of consumers when tasting freshwater prawns of such poor quality led to a steady decrease in interest, both on the part of consumers and of wholesalers for this new product. The name 'Camarão Gigante', which means 'giant prawn' was very bad for the image of *Macrobrachium* because consumers were led to expect a very large prawn, not the 40 to 80 g prawns commonly available from farms.

A large farm was set up in Alagoas State in the 1980s, called Capiatã. This farm decided to produce small prawns (about 12 to 20 g) in order to attain three production grow-out cycles annually. Prawns were marketed as good quality, whole, frozen prawns. An advertisement programme was started. The name of the product was changed to 'Camarão Capiatã' and brochures were delivered containing information on handling and cooking freshwater prawns. This farm obtained good results and marketed more than 20 t/month to supermarkets for a long time. Unfortunately, problems other than marketing have since caused the closure of this farm.

In 1990, in the State of Rio de Janeiro, 65 farms were producing about 120 t of freshwater prawns from 120 ha of ponds. These farms faced the same problems as described above and most of them ceased their activities. Rio de Janeiro is an important marine shrimp fishing and marketing area. Most consumers were confused between the big 'jumbo' penaeids which they saw at the fish market and the largest freshwater prawns. The biggest farm in the State, Fazenda Santa Helena, therefore decided to completely change their marketing strategy. They geared the management of their ponds towards the production of small animals of 10 g each. This strategy resulted in:

- a production grow-out cycle of 4 months;
- higher stocking densities;
- a reduction in production costs;
- easier handling;
- better tail/head ratios;
- more similarity with marine shrimp; and
- a lower FCR, closer to 1:1.

This change in the marketing policy of the farm proved very successful. Additionally, four other factors have played an important positive role: (1) the reliability of production increased; (2) the farm is close to a highway, which facilitates advertising and farm-gate sales; (3) visitors can taste what they see in a small restaurant near the farm; and (4) the owner lives on-farm, which has resulted in better control of product quality.

19.7.2 Costa Rica

When the prawn farm Langostinos Koko ('Koko') began to market in Costa Rica, the reputation of the product was not good. An existing farm had been drain-harvesting freshwater prawns, freezing them and trying to sell them at a premium price. They failed to achieve sales at this price so, after a number of months, they began to sell a product that still looked nice but which had definite quality problems, to the local market at a significantly reduced price. The reason for the rapid deterioration of the product had to do with the frequent loss of electrical power and the repeated freezing and unfreezing of the prawns.

Koko set out to change this image. Firstly, the farm shifted to a seine-harvesting programme to make fresh product available twice a week. Secondly, it marketed about 85% of its product fresh, 5% live and 10% frozen. The farm also purchased a freezer that freezes at –35°C, to improve the quality of the frozen product. Koko hired a talented chef to visit restaurants and hotels to demonstrate how to prepare the product in ways that would enhance the quality image and the profitability of the product to the restaurant or hotel. It also developed a large bank of recipes (examples given in section 19.8.2) for home and restaurant use and then took samples to the supermarkets and worked with them to sell the product. At first, only the markets with fish sales departments sold the product; these helped to determine sizes and pricing strategy. Koko eventually decided to charge almost the same price as premium marine shrimp. The pricing strategy affects the customer's perception regarding the quality of the product. Currently, the product is in demand throughout Costa Rica and the farm is planning an expansion in production to meet the increasing demand.

One of Koko's most loyal customers had been using wild-caught prawns (*M. carcinus*) caught in the rivers of Nicaragua. These river prawns are very large, usually over 300 g, and relatively firm in texture. The flavour is strong but good, a fine product for any seafood restaurant. At first, this restaurant owner was very disappointed with the farm-raised *M. rosenbergii*, which seemed 'mushy' and did not have a strong flavour. In appearance it was very similar to the river prawns he was accustomed to but it needed different handling. Koko supplied recipes (see section 19.8.2) and handling instructions (Table 19.1) and then demonstrated cooking techniques in his kitchen. The restaurant owner remained unconvinced until he ran out of the river prawns and ran short of lobsters. He found most of his lobster dishes could be made with *M. rosenbergii* and, with proper seasoning and handling, the product was noticeably more consistent than the river prawns. Now he is a regular customer of the Koko farm.

19.7.3 French Guiana

In 1987 a marketing study prepared by professionals in close co-operation with the *Macrobrachium* producers' co-operative, IFREMER, and the Ministry of Agriculture, determined that a potential niche existed for this species on the French mainland. The production of *Macrobrachium* had exceeded the capacity of the local market in French Guiana (see 19.2.1). The goal for the first year was to try to sell 2 t of fresh product per month, to various supermarkets around Paris, at double the price of the international (frozen) market. A managing director was hired for the French mainland to control the preparation of support activities (leaflets, recipes, presentation packs to supermarket purchasing managers, etc.) and to supervise the follow-up of the whole commercial launch. The first test year was a success, and the producers exported up to 5.5 t/month. This tremendous effort of organisation and management ended in November 1990 with a total of 78 t exported in 2 years (i.e. 43% of the Guianese production), at twice the average global price, with an excellent acceptance by both supermarkets and consumers. However, the producers were not able to finance their further expansion. It also became obvious that the lack of a reliable infrastructure in this country was a permanent and significant handicap: ice machines, power, and clean storage facilities were expensive to secure, particularly as most of the farms were in the rainforest, a 3-hour truck drive from the airport. There are two basic questions (P. Sandifer, pers. comm. 1988) that every aquaculture investor has to answer, in this order:

- Can you sell what you want to grow?
- Can you grow what you can sell?

19.8 Preparing freshwater prawns for consumption

This book mainly concerns the science and, where the science is deficient, the art of culturing, harvesting, processing and marketing freshwater prawns. The ultimate aim of all these activities is to create a product that is nutritious and delectable for human consumption. Unless this fact is recognised, there is no prawn farming industry, and no reason for further research. For these reasons, some information about the use of the final product is relevant. Section 19.8.1 provides some recommendations for handling and storage, mainly intended for restaurateurs, and section 19.8.2 contains examples of the ways in which freshwater prawns can be incorporated as the major ingredient of typically delicious recipes. Finally, some notes on the microwave cooking of freshwater prawns are given in section 19.8.3. Figure 19.3 and Plate 6 (facing p. 220) illustrate some cooking techniques.

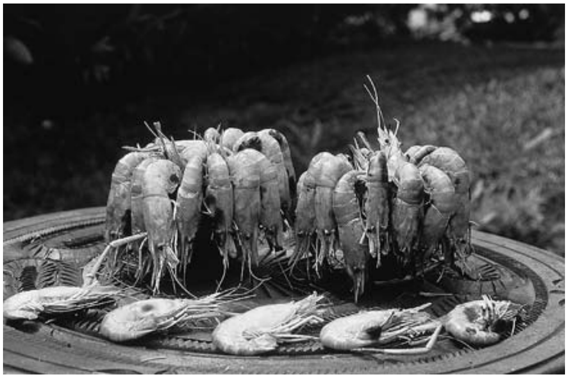

Fig. 19.3 Barbecue presentation of freshwater prawns. (Source: Denis Lacroix.)

19.8.1 General recommendations

Freshwater prawns require care in handling and storage (Table 19.1). In many countries they are traditionally cooked whole but in others it is more common to cook prawns that are purchased as tails. Cooking the whole animal preserves the natural juices and delicate flavour of the prawn. Freshwater prawns have variously been reported to have a negligible content of iodine (J. Glude, pers. comm. 1992) or a lower content than marine shrimp (Chapter 18); this attribute may have advantages for those consumers who are allergic to food with high iodine content. Since there is very little salt in the meat of freshwater prawns it will accept the flavours you add more readily. If you wish to duplicate the flavour of marine shrimp more salt will be needed. The following techniques will enhance the flavour and presentation of freshwater prawns.

It is best to prepare the prawns immediately upon removing them from the refrigerator or freezer. Do not allow them to stand at room temperature for extended periods of time. Whole freshwater prawns may be prepared from the frozen state. The natural juices are sealed in and the meat is firm, moist, and flavourful. Separate frozen prawns by rapping the package lightly on a hard surface. Remove only the amount required and replace the remaining prawns in the freezer immediately. To thaw, place prawns under cold running water for 2 or 3 minutes.

Freshwater prawns, unlike marine shrimp, do not have a highly visible vein that requires cleaning. However, if cleaning is desired, simply snip with kitchen shears down the back of the shell and rinse under cold water. For attractively serving whole prawns, you may wish to trim the antennae and front claws, but it is not necessary. To remove the shell before or after cooking, either snip the shell down the back or grasp the bottom edge where the shell connects with the legs and peel. The shell should come off easily in large pieces.

To marinate, thaw frozen prawns or remove them from ice, marinate in oil and vinegar, Italian-style dressing, or wine. Be sure to keep the prawns refrigerated so that they will remain firm until time for preparation.

There is an infinite variety of delicious ways to cook freshwater prawns. If boiling them, bring the stock or water to a brisk boil before adding the prawns. Some cooks add a 'shrimp boil' or 'Old Bay Seasoning'. From the frozen state, cook the prawns for 5 minutes. If thawed, cook for 4 minutes. Freshwater prawns can be cooked in boiling water like lobsters, grilled, barbecued, or baked whole. Another method of preparation is to slit along the back and through the top of the head, spread open gently, and baste or stuff with a dressing of choice. Grill thawed prawns for 2.5 to 3 minutes per side. Bake thawed prawns for 12 to 15 minutes at 180°C. You may sauté or barbecue prawns. Sauté for 5 minutes or barbecue six inches (15 cm) from heat for 7 to 8 minutes.

It is also possible to microwave freshwater prawns (see section 19.8.3). Place the frozen prawns in a single layer in a covered container along with any desired seasoning. Cook on high for 3 minutes or until the shell turns pink.

When using any of the above methods, your cooking time may vary depending on the size of the prawns and your cooking equipment. Usually, prawns are ready to serve when their shells turn pink.

Some cooking and serving hints are provided below:

- Prawns have the best flavour and texture when they are cooked with the head and shell intact.
- If the recipe does not call for whole prawns, save the heads (in your freezer) for soup stock and prepare the tails as recommended.
- Before serving prawn tails in their shells, snip the underside of the shell with kitchen scissors, two-thirds of the length of the tail. This makes it easier for your guests to remove the meat from the prawn.
- A popular method of cooking prawns is to simmer them in salted water. The recommended ratio of salt to water is approximately 4 teaspoons per kilogram of whole prawns.

19.8.2 Traditional recipes

A series of sample recipes that can be prepared by ordinary restaurants or in the home to produce delicious meals with freshwater prawns (sometimes referred to as langostinos) have been provided in this section. In each case, the origin of the recipe has been noted below its title. Some notes on producing meals with freshwater prawns by microwave cooking are provided in section 19.8.3.

In general, measurements of weight have been converted to metric. The measurements of volume named 'teaspoon' and 'tablespoon' have been retained, since they are internationally accepted. The measurement of volume called a 'cup' is typically American but has been retained in these recipes (obviously, since food density is very variable the weight of different ingredients defined as a 'cup' will not be the same). Cooking is an art, not a science, so these measurements are not precise. For guidance, a 'cup' may be defined as approximately 250 ml.

Barbecued Prawns (Puerto Rico)

Yield: 4 servings; Preparation time: 20 minutes; Cooking time: 10 minutes

1 kg whole freshwater prawns
125 g butter
2 cloves garlic

Place whole prawns on hot barbecue about 15 cm from the coals. Brush with garlic butter mixture. Cook for 7 to 8 minutes, turning occasionally.

Cantonese Fried Prawns (China)

Yield: 4 to 8 servings; Preparation time: 1.5 hours; Cooking time: 5 minutes

500 g whole prawns in the shell
2 cups water
Salt to taste (about $2\frac{1}{2}$ teaspoons)
1 teaspoon freshly ground white or black pepper
$\frac{1}{4}$ teaspoon sugar
Peanut, vegetable, or corn oil for deep frying

(1) Do not shell the prawns, but use a pair of kitchen scissors and cut off the small legs on the underside. De-vein if desired by cutting open a small section of the back and pulling out the vein with a skewer or toothpick.
(2) In a mixing bowl, combine the water with about 2 teaspoons salt. Add the prawns and let stand about 1 hour. Drain and pat with a clean cloth or paper towelling until very dry.
(3) Combine $\frac{1}{2}$ teaspoon salt, the pepper, and sugar and set aside.
(4) In a wok or deep-fryer, heat the oil and add the prawns. Fry, stirring, for no longer than 1.5 minutes.
(5) Drain the prawns in a sieve-lined bowl and pour off the oil from the pan. Do not wash the pan.
(6) Return the prawns to the pan and sprinkle with the salt and pepper mixture. Toss over a high heat for about 15 seconds. Spoon into a serving dish and serve plain.

Ceviche (Common in Latin America; this recipe is from Langostinos Koko, Costa Rica)

Yield: 8 to 12 servings as an appetiser with cracker biscuits; Preparation time: 1.5 hours

1.5 kg of freshwater prawns peeled, de-headed, and de-veined, chopped into 2.5 cm pieces
4 tablespoons chopped coriander
1 cup lime juice (ginger ale can be used)
2 tomatoes, peeled, seeded and chopped
2 to 4 chillies, seeded and chopped (Tabasco sauce can be used as a substitute)
Thin slices of red onion or scallion for garnish (also a little chopped onion can be used)
8 to 12 packets of cracker biscuits

In a small stainless steel or glass bowl, combine the freshwater prawns, chillies and coriander. Cover with lime juice, tossing the prawns to moisten pieces evenly. Cover and refrigerate at least 1 hour. Fifteen minutes before serving, add the tomato and salt to taste. Garnish with onion or scallion slices. Ceviche can be served in glasses, on a bed of greens or in avocado halves. Some sea bass, dorado, or other whitefish can be added. The hot sauce can be deleted and replaced with chopped onions and avocado. This can be stored for 2 days in the refrigerator. Serve with a packet of crackers per person.

Chinese Prawns (China)

Yield: 2 to 3 servings; Preparation time: 2.5 hours; Cooking time: 6 minutes

750 g whole freshwater prawns
2 teaspoons peanut oil
3 cloves garlic, finely chopped
2 teaspoons vegetable oil

Slit the tail lengthways, leaving the head intact. Combine garlic, salt, and peanut oil, rub oil mixture into exposed tail meat. Refrigerate for 2 hours. Stir-fry with vegetable oil for 5 to 6 minutes.

Grilled Prawns (French Guiana)

Yield: 6 servings; Preparation time: 10 minutes; Cooking time: 15 minutes

1.5 kg blue prawns
3 cups of rice
4 tablespoons of olive oil
2 teaspoons of saffron
1 teaspoon of turmeric
Salt and pepper to taste
Juice of one lime

Prepare a marinade with olive oil, saffron, turmeric, lime juice, salt and pepper. Let the prawns marinate for 4 hours in the refrigerator; stir every 30 minutes. Prepare rice: slightly sticky. Grill for 3 minutes (1.5 minutes on each side) and serve on a bed of rice.

Medley of Seafood Soup (Louisiana)

Yield: 6 servings; Preparation time: 30 minutes; Cooking time: 25 minutes

2 medium carrots, thinly sliced
1 tablespoon olive oil
1 medium green pepper, coarsely chopped
2 garlic cloves minced
1 medium onion, chopped
1 can (400 g) whole tomatoes, crushed
1 cup white wine
$\frac{1}{2}$ tablespoon *each* of grated lemon rind, Tabasco sauce, dried basil, dried thyme and salt
1 bay leaf
250 g grouper fillets, cut into 2.5 cm pieces
250 g sea scallops (or conch)
500 g freshwater prawns, de-headed, peeled and deveined (save the heads)
12 whole clams or whole mussels, shell on
2 tablespoons lemon juice

(1) In a 1-litre microwave-safe casserole put the prawn heads and two cups of water. Cook on medium for 5 minutes. Discard heads but save the stock.
(2) In 3-litre microwave-safe casserole combine the carrots, green pepper, onion, garlic and olive oil. Cook on high (100%) for 5 minutes or until vegetables are tender. Add prawn stock, tomatoes, wine, bay leaf, lemon rind, Tabasco sauce, basil, thyme, and salt. Cover loosely with plastic wrap. Cook on high power for 5 minutes or until clams open and seafood is tender. Remove bay leaf. Stir in lemon juice.
(3) Serve with crusty-spicy bread (made by stirring together in a small bowl 1 cup softened butter, $\frac{1}{2}$ cup grated Parmesan cheese and 2 teaspoons Tabasco sauce until well blended. Cut 1 loaf of French bread into 1-inch slices. Spread with butter mixture. Grill until bubbly and lightly browned).

Paella (Spain)

Yield: 6 servings; Preparation time: 30 minutes; Cooking time: 1 hour

1.5 kg whole freshwater prawns
6 clams
1 cup chopped lobster meat
1 kg pieces of chicken, fish, or rabbit
1 teaspoon salt (optional)
1 cup water
$\frac{1}{4}$ teaspoon pepper
3 tablespoons olive oil
$\frac{1}{4}$ teaspoon oregano
$\frac{1}{2}$ cup chopped onion
$1\frac{1}{2}$ cups long grain rice
$\frac{1}{4}$ teaspoon saffron
2 cans (400 g each) chicken broth
1 clove garlic minced
300 g frozen peas
3 sweet peppers, in strips

Remove tail shell, leaving head intact, and clean prawns. Wash clams. Season chicken pieces with salt, pepper, and oregano. In a large skillet, heat olive oil and brown chicken pieces. In a bowl combine rice, chicken broth, water, onion, garlic and saffron. Pour mixture over the chicken pieces and stir, being sure all of the rice is in the liquid. Cover and bring to the boil. Lower heat and simmer for 20 minutes. Add prawns, clams, peas, and peppers. Cover and cook for 10 more minutes. Allow to stand for 20 to 25 minutes before serving.

Prawn Creole (Puerto Rico)

Yield: 4 Servings; Preparation time: 20 minutes; Cooking time: 15 minutes

$\frac{1}{2}$ cup celery
1 can (400 g) tomato purée (cubed tomatoes can also be used)
$\frac{1}{2}$ cup green pepper
1 kg whole freshwater prawns
$\frac{1}{2}$ cup onion
1 teaspoon salt
2 tablespoons vegetable oil
$\frac{1}{4}$ teaspoon pepper
Hot pepper sauce

Finely chop celery, green pepper and onion and combine them with tomato purée in a 2-quart casserole with garlic. Set microwave power select at high and heat for 4 to 5 minutes or until vegetables are tender. Clean and shell prawns. Stir prawns, salt, pepper, and hot sauce to taste into vegetables. Cover with glass lid. Set power select at high for 3 minutes and then medium for 5 to 6 minutes. Stir once during cooking. Stir. Let stand, covered for 5 minutes before serving.

Prawn Gumbo (Louisiana)

Yield: 4 servings; Preparation time: 25 minutes; Cooking time: 35 minutes

$\frac{1}{4}$ cup butter or bacon fat
2 teaspoons salt
1 medium onion
1 teaspoon ground nutmeg
2 tablespoons cornstarch
$\frac{1}{4}$ teaspoon pepper
1 cup water
1 kg whole freshwater prawns
2 cans (500 g each) stewed tomatoes
2 cloves garlic
2 packets (300 g each) frozen okra
Crab boil (found in condiment section of USA supermarkets)

(1) Slice onion, dice green pepper, and crush garlic. Shell and de-vein prawns. Defrost the okra and slice into 2.5 cm pieces.
(2) Place onion in 3-litre casserole with butter. Microwave on high for 3 minutes or until onion is limp. Stir after 2 minutes.
(3) In small bowl, stir together cornstarch and water. Add to onion along with tomatoes, green pepper, garlic, salt, nutmeg, pepper, prawns, and okra. Stir well. Cover and microwave at medium for 14 to 16 minutes until prawns are cooked and mixture is hot.
(4) For spicy flavour, tie 1–2 teaspoons crab boil in a cheesecloth bag and add along with prawns. For bright colour accent, save out about $\frac{1}{4}$ cup of green pepper to stir into finished gumbo.

Prawn Scampi (Hawaii)

Yield: 4 servings; Preparation time: 20 minutes; Cooking time: 25 minutes

1 clove garlic
$\frac{1}{2}$ teaspoon salt
$\frac{1}{3}$ cup butter or margarine
375 g medium freshwater prawns, cleaned
$\frac{1}{4}$ cup chopped parsley
1 teaspoon lemon juice

In a 1-litre casserole, combine the garlic and butter. Set microwave power select at high and heat for 2 minutes. Add parsley and salt. Stir in cleaned, raw prawns, coating each with butter sauce. Cover with plastic wrap. Set power select at medium for 6 minutes and low for 2 minutes. Stir once. Let stand, covered for 3 minutes. Sprinkle lemon juice over prawns before serving.

Prawns with Herb and Lemon Butter (California)

Yield: 4 servings; Preparation time: 30 minutes; Cooking time: 15 minutes

$\frac{1}{4}$ cup butter or margarine
$\frac{1}{4}$ teaspoon salt
$\frac{1}{2}$ teaspoon basil
500 g freshwater prawn tails
$\frac{1}{2}$ teaspoon crushed rosemary
1 lemon
Paprika

Set microwave power select at high. In a 20-cm round baking dish, heat the butter, basil, rosemary, and salt for 1.5 minutes, or until butter melts. Stir in shelled, cleaned prawns and sprinkle with lemon juice. Spoon butter mixture over prawns. Cover with microwave-friendly plastic wrap. Set power select at medium for 7 to 8.5 minutes. Prawns should be tender. Sprinkle with paprika. Let stand, covered, for 5 minutes before serving.

Prawns with Pineapple (Hawaii)

Yield: 6 to 8 servings; Preparation time: 20 minutes; Cooking time: 30 minutes

Batter:

1 cup flour
1 tablespoon sugar
$\frac{1}{2}$ teaspoon salt
1 egg
$\frac{2}{3}$ cup water

Sauce:

3 tablespoons brown sugar
1 tablespoon cornstarch
1 teaspoon salt
2 tablespoons vinegar
$\frac{1}{3}$ cup water
$\frac{3}{4}$ cup pineapple juice
2 cups salad oil

1 kg freshwater prawns, de-headed, shelled, and de-veined
1 can (500 g) pineapple chunks

Prepare batter by mixing the dry ingredients together. Beat egg slightly and add water. Mix into dry ingredients. Dip prawns in batter and deep fry in hot oil until golden brown; set aside. Make sauce by combining all sauce ingredients. Bring to boil and simmer for 1 minute. Place pineapple chunks on platter with prawns. Cover with sauce. Serve.

Salad of Prawns with Salmon Eggs (France)

Yield: 6 servings; Preparation time: 15 minutes; Cooking time: 15 minutes

1.5 kg whole prawns
100 g of salmon eggs
500 g various vegetables (e.g. carrots, French beans)
1 tomato
1 lettuce
Basil pieces
3 tablespoons of olive oil
Wine vinegar
Salt, pepper

Cut vegetables in small pieces and cook them in boiling water (7 minutes for beans, 11 minutes for carrots). Cut the head off the prawns; peel the tails. Pour the olive oil and basil in a pan and cook the tails in this mixture for 1.5 minutes on each side. At the end, prepare a lukewarm sauce with vinegar, tomato cubes, basil, salt and pepper. Place the prawns and the vegetables on a dish and poor the sauce over the prawns and add the salmon eggs on the side. Serve.

Spicy Boiled Prawns (Puerto Rico)

Yield: 3 to 6 servings; Preparation time: 30 minutes; Cooking time: 15 minutes

$1\frac{1}{2}$ cups water
2 ribs celery, chopped
10 whole allspice berries
$\frac{1}{4}$ teaspoon ground mace
5 cloves garlic
1 bay leaf crushed
2 sprigs fresh parsley
2 teaspoons fresh thyme *or* $\frac{1}{2}$ teaspoon dried leaf
1 kg whole prawns

$\frac{1}{2}$ teaspoon *each* of salt and red pepper flakes
$\frac{1}{4}$ teaspoon *each* of cayenne pepper and freshly ground black pepper

Put all ingredients except prawns in a 2.5-litre casserole. Cover. Microwave on high (100%) power until boiling for 6 to 8 minutes. Stir in the prawns, pushing them to the outer edges of the dish. Cover. Microwave on high power until prawns are just pink (3 to 5 minutes), stirring every 30 seconds. Let stand 1 minute to cool slightly, then serve prawns in a large bowl or individual bowls and let guests peel the prawns themselves.

Steamed Hawaiian Prawns (Chef Tylun Pang of Westin Iliki Hotel, Hawaii)

Yield: 4 servings; Preparation time: 30 minutes; Cooking time: 10 minutes

16 Hawaiian prawns (size 8–12/kg)
1 green onion
Half a leek
Half a medium-sized finger of fresh ginger
1 carrot
3 cloves garlic
2 stalks of celery
1 tablespoon sesame oil
Salt to taste
Rice vinegar
Soy sauce
Sesame oil
Korean-style hot sauce

To prepare the main dish:
Trim antennae, claws and legs from the prawns. Peel and de-vein the tails. Julienne the leek, carrot, celery and green onions. Finely chop the ginger and garlic. Line the prawns on the serving platter; sprinkle with salt, part of the ginger and garlic, and sesame oil. Place platter on a bamboo steamer; cover and steam on top of a pot of steaming water. Cook until the prawns are done, about 5 to 7 minutes. Serve with dipping sauce.

To make the dipping sauce:
(1) Combine 250 ml of soy sauce with 1 tablespoon of Korean-style hot sauce.
(2) Combine the rest of the finely chopped garlic cloves with the remainder of the finely chopped ginger and 250 ml rice vinegar.

Steamed Prawns (Puerto Rico)

Yield: 3 servings; Preparation time: 20 minutes; Cooking time: 10 minutes

1 kg whole freshwater prawns
3 tablespoons soy sauce
2 teaspoons sesame oil
$\frac{1}{2}$ tablespoon ginger juice
1 dash white pepper

Slit the tail lengthways, leaving the head intact. Place the prawns slit side up in a pan suitable for steaming. Combine remaining ingredients and add to prawns. Steam for 6 to 8 minutes. Serve.

Szechuan Prawns (China)

Yield: 4 to 8 servings; Preparation time: 10 minutes; Cooking time: 15 minutes

1 kg whole prawns
$\frac{1}{2}$ cup finely minced fresh ginger
2 tablespoons chopped garlic
1 cup fermented rice
$\frac{1}{4}$ cup shredded or cubed fresh red or green long hot peppers
1 tablespoon plus one teaspoon dark soy sauce
1 tablespoon light soy sauce
$\frac{1}{2}$ teaspoon sugar, or to taste
Salt to taste
$\frac{1}{2}$ teaspoon monosodium glutamate (optional)
125 g ground pork
1 litre peanut, vegetable, or corn oil
1 cup water
2 tablespoons chilli paste with garlic (Szechuan Paste)
Hot oil to taste (optional)
1 bunch scallions, chopped (about 1 cup), green part included

(1) Do not peel the prawns. Using scissors or a sharp knife, cut through one section of the back of the shell without cutting the vein. Pull out the vein of each prawn (optional) with a toothpick or skewer and discard. Wash the prawns

well, cut off and discard the feet and drain. Pat the prawns dry.

(2) In a small bowl, combine the ginger, garlic, and hot peppers and set aside.

(3) In another bowl, combine the fermented rice, soy sauce, sugar, salt to taste, and monosodium glutamate.

(4) Heat the oil in a wok or skillet and add the prawns. Cook, stirring, until they turn pink, about 1.5 minutes. Drain the prawns in a sieve-lined bowl to catch the drippings and pour off all but about 5 tablespoons of oil from the pan. Add the pork to the oil in the pan and cook, stirring, just until the strands of pork are separated and the pork looses its pink colour. Add the chilli paste with garlic and cook, stirring for about 1 minute. Add the ginger and garlic mixture and cook, stirring, for about 45 seconds.

(5) Add the fermented rice mixture and cook for about 15 seconds. Add the water and $\frac{1}{4}$ cup of the scallions. Bring to a boil, stirring, and cook for about 3 minutes, or until the sauce is slightly thickened. Add the prawns and remaining scallions. Cook for about 1 minute, stir in the hot oil, if used, and serve.

Tangy Saucy Prawns (California)

Yield: 4 servings; Preparation time: 20 minutes; Cooking time: 15 minutes

$\frac{1}{2}$ cup chilli sauce
$\frac{1}{2}$ cup beer
$\frac{1}{2}$ cup pickle relish
250 g medium-sized prawn tails

(1) Set microwave power select at high. In a medium-sized glass bowl, combine the chilli sauce, pickle relish, and beer. Cook for 3 to 4 minutes, stirring once.

(2) Set power select at medium. Heat for 10 minutes or until sauce is thickened, stirring occasionally. Stir in cleaned and shelled prawns. Heat for 3 to 4 minutes at medium or until prawns are tender, stirring once. Let stand, covered, for 2 minutes.

(3) Serve by arranging on small plates, or skewer with picks.

19.8.3 Microwave recipes

A handful of unshelled raw prawns can be cooked in less than a minute in the microwave oven, without boiling water, without any fat and without any extra dishes or pans to wash. Convenience alone is thus reason enough to try your hand at prawns in the microwave. But a little technique is helpful. The most important advice is the same as with conventional cooking; do not overcook the prawns. When the prawns curl and just turn pink they are done. More cooking will just make them tough.

To avoid overcooking prawns in the microwave, arrange them on a plate with tails facing in, cover with a plastic wrap, and microwave on high (100%) power using the timing guidelines that follow, until the prawns just turn pink, stirring and rotating several times.

Using small amounts of prawns, about 125 g, will give the most consistent cooking results in the microwave. For 250 g of medium-sized prawns, make concentric circles of the prawns on the plate and turn each prawn after 1 minute, then again in 30 seconds.

Five hundred grams of prawns need to be tossed and rearranged in a covered casserole at least every minute to be sure they are cooked evenly. And still you may find one or two undercooked prawns hidden in the pile. Pull out these undercooked prawns, place them on a plate and give them an extra 20 seconds, or as needed. The size of the prawns doesn't matter. Jumbos of 250 g take the same time as 250 g of mediums. However, if you butterfly the prawns they take about a minute less per 500 g.

To butterfly prawns, de-head, shell and de-vein. Then use a small knife to cut in about 6 mm along the back edge, stopping at the tail. Press body flat. When the prawn cooks it will curl into a butterfly shape. (Note: save the heads for bisque or prawn soup).

Microwave timing for freshwater prawns

Unshelled:
125 g: 45 seconds to 1 minute
250 g: 2 to 2.5 minutes
500 g: 3 to 3.5 minutes
Shelled:
125 g: 1 to 2 minutes

250 g: 2 to 3 minutes
500 g: 3 to 3.5 minutes

Butterflied:

125 g: 30 to 35 seconds
250 g: 1 to 1.5 minutes
500 g: 2.5 to 3 minutes

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20
Economics and Business Management

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Establishing or expanding a commercial freshwater prawn cultivation enterprise requires a significant amount of time and financial resources. Unfortunately, economic and financial feasibility techniques are sometimes applied only after significant commitments have been made to a selection site and production techniques. Financial feasibility analysis should not be viewed as an afterthought for justifying the financial viability of the proposed enterprise or of aquaculture research intended to assist private sector efforts (Neiland 1994). Instead, financial analysis should be an integral part of evaluating the overall viability of an aquaculture enterprise and related technologies, alongside the consideration of various alternatives such as site selection, production techniques, and marketing strategies.

This chapter, therefore, focuses on the financial aspects of freshwater prawn culture in the private sector, with an emphasis on the costs and returns of commercial prawn farming. Those interested in a public sector perspective on aquaculture development should review Maine & Nash (1987) and other documents (Lee & Wickins 1992; NRC 1992; Pillay 1994). The focus on the private sector aspects of commercial prawn farming in this chapter does not imply that financiers and entrepreneurs of an aquaculture enterprise should be indifferent to the socio-economic environment of the country and community hosting their project. Obviously, documenting and projecting the socio-economic benefits (e.g. domestic employment and income) generated by an aquaculture enterprise could be critical to securing public sector assistance such as government aid, guaranteed loans, and site permits. In addition, those involved in an aquaculture enterprise may need to address the likely socio-economic and environmental costs of their enterprise, from both a local and national standpoint. Local community acceptance of a new aquaculture project could be as critical as biophysical and infrastructure factors when selecting potential sites.

20.1 Aquaculture business planning and management

In a rapidly changing world, business planning has become critical to mitigating the risks associated with developing and managing a business enterprise. This risk minimisation orientation stems from the unstable environment in which the enterprise resides. Furthermore, the enterprise operates within a market-oriented environment, competing with other similar enterprises for consumers and various resources (e.g. feed, labour, etc.). Consequently, business planning must address the interdependency between the business environment and the enterprise, so that the organisation can try to influence or adapt to change.

If funding for a new or existing aquaculture enterprise is being sought, a written business plan is usually considered critical for obtaining funds. In any case, there are several reasons for producing a written business plan. Firstly, the process of preparing a business plan forces all parties involved to make a comprehensive evaluation of the business project and of how identified objectives will be accomplished. Secondly, a written business plan can be an outline to help start and manage an aquaculture enterprise. Finally, a written business plan provides details, which may be required by lenders and investors if there is a need to obtain external financing, either for new or existing enterprises.

There are numerous variations of business plans, and the emphasis within the plan should vary depending upon the kind of financing anticipated, the technical nature of the business (e.g. low-tech *versus* high-tech), and the current status of the business (e.g. start-up, expansion) (ABA 1995). In general, an aquaculture business plan should address aquaculture technology, marketing, management and, last but not least, financial considerations. Approaches to preparing business plans specifically tailored for aquaculture enterprises can be found in Rhodes (1984), ABA (1995) and other publications. It should be noted that the executive summary of a written business plan can be critical. For those evaluating the plan, it can 'test' how concise the aquaculture developers are in successfully communicating their goals and financial needs. For the aquaculturist preparing the plan, its summary allows reviewers, who are often occupied with reviewing many other proposals (ABA 1995), to quickly understand their financial needs and business goals.

20.1.1 Business management and staffing

The success of freshwater prawn aquaculture grow-out enterprises, like a marine shrimp farming venture, is often dependent upon five critical factors: (1) site selection, (2) business management, (3) availability/source of seed stock, (4) facility design and construction (IFC 1987), and (5) marketing strategy. Except for the management of aquaculture enterprises, these factors have been addressed in other chapters of this book. Unfortunately, the overall management of private aquaculture enterprises has not received much research attention. For example, in the USA, most small businesses do not survive the first 2 years, mainly because of the founding entrepreneur's inability to manage a new enterprise (Kuriloff & Hemphill 1981). Moreover, Leeds (1986) contended that aquaculture enterprises will succeed or fail because of the '. . . quality of the management and technical personnel . . .' rather than technical and market-related reasons. An individual or a group organising a new enterprise must identify and recruit appropriate technical and managerial personnel.

In the case of small aquaculture enterprises, the owner-operator needs to recognise his/her limitations. For large aquaculture projects, recruiting technically qualified managers and technicians with sufficient experience to operate commercial-scale farms in developing countries may sometimes be difficult, and it may be advisable to seek expatriate assistance (IFC 1987). Extensive training programmes may also be needed to develop management and technical expertise. Consequently, start-up investment costs for freshwater prawn farms may need to include projected expenditures for training activities such as workshops. Pre-production training costs for implementing large enterprises involving complex technology in developing countries have represented 10 to 15% of project initial investment costs in some cases (Behrens & Hawranek 1991).

A manager or management team with experience in marketing and small business management would have the capability to handle a wide variety of start-up and operating problems. If the enterprise is managed by a team (e.g. the founding entrepreneurs, etc.), the management structure usually needs to include a division of responsibilities for various critical functions, especially in the management of daily production operations and marketing. Small and large aquaculture projects, like other commercial enterprises, may need to have marketing tasks and operations management delegated to different individuals (Rhodes 1991). Ironically, the behaviour patterns of founding entrepreneurs may not be conducive to the everyday management of commercial enterprises (Kuriloff & Hemphill 1981).

20.1.2 Marketing considerations

The marketing function in aquaculture ventures is probably the most neglected but one of the most critical to the firm's success. Approaches to marketing aquaculture products can be found in several publications (Chaston 1983; Shaw 1986; Meade 1989). The development or expansion of aquaculture market segments is partially predicated on understanding consumer preferences, market channels and other market variables (i.e. effective marketing research). Business researchers have noted that entrepreneurs tend to de-emphasise obtaining in-depth marketing information for their business plans prior to start-up, even though US venture capitalists believe that in-depth marketing analyses are quite valuable and that new venture failure rates could be reduced via improved advance analysis (Hill 1985). The sales forecasts used in pro forma statements are only as good as demand forecasts developed from market analysis. In the case of export marketing, careful research must be done beforehand (Stoner & Arora 1983). Unfortunately, new aquaculture enterprises, including those cultivating freshwater prawns during the 1970s, have apparently suffered from the lack of adequate marketing research and analysis (Chaston 1983). Perhaps aquaculture entrepreneurs become so involved in culturing and post-harvesting techniques that they de-emphasise market analysis and strategies. As Shang (1990) noted on the role of marketing in commercial aquaculture:

> 'A species has the potential for commercial development only if there is a ready market for it at prices that provide reasonable profit and if the marketing infrastructure and channels are adequate for and efficient in handling increased production.'

Commercial aquaculture is market driven, so the first priority for a feasibility analysis is to analyse current and potential markets for a proposed species (Shang 1990). Even for public sector funding of commercial bio-technical aquaculture research and development (R&D) projects, effective market analysis should be done before committing to significant funding of aquaculture R&D and related extension programmes (Hatch & Kinnucan 1993).

20.1.3 Financial feasibility analysis

A financial feasibility analysis usually starts with an examination of net income (profit and loss) statements, balance sheets, and cash flow budgets, whether it involves the rehabilitation or expansion of an existing enterprise or a new venture. The techniques used in preparing these various statements (budget) are a subject beyond the scope of this chapter. There are numerous books available on this subject, and various microcomputer software is very handy when preparing statements and associated projections.

Before reviewing techniques for analysing and evaluating the financial feasibility of an aquaculture project, it is important to note that financial statements represent only a single dimension in evaluating the financial viability of an aquaculture venture. The application of the various quantitative techniques used to analyse the financial feasibility of a proposed commercial enterprise sometimes obscures the real multiple objectives or criteria that a financial feasibility analysis may be subject to. A financial feasibility analysis also needs to recognise the interests of involved parties beyond the expected net benefits of an isolated investment. For example, a joint-venture partner may expect additional cash flows as an investor, perhaps due to royalty payments on certain technology or complementary marketing arrangements (Behrens & Hawranek 1991). In essence, the interests of investors and lenders may constitute a wide array of objectives, which need to be identified and addressed in the financial feasibility analysis, preferably in monetary terms.

Although projected income statements and balance sheets are useful tools, discounted cash flow (DCF) analysis is the generally accepted approach to financial feasibility analysis (Behrens & Hawranek 1991). Discounted cash flow analysis is based upon the assumption that money has a time value. Therefore, a sum of money received or paid now is worth more than the same sum available in the future. The future value of the sum is determined by an interest or 'discount' rate. Financial analysis textbooks and other publications should be consulted for more details.

Rhodes (1991) summarised the application of DCF analysis in the context of evaluating aquaculture projects. The two main DCF analytical methods are the net present value (NPV) and the internal rate of return (IRR) methods. The modified internal rate of return (MIRR) has replaced the IRR method when analysing aquaculture projects (Rhodes *et al.* 1995). The modified internal rate of return is a more realistic measure of profitability because it assumes that net cash flows from all investment projects are reinvested at the cost of capital, while the IRR assumes that cash flows are reinvested at the project's own IRR (Brigham & Gapenski 1988). A 'hybrid' DCF analysis technique, the discounted payback period (DPP), is also recommended (Rhodes 1991). The traditional payback (PB) method, which is used to determine the amount of time, usually years, in which an aquaculture enterprise should recover its initial investment, has two disadvantages:

(1) it ignores cash flows after the payback period; and
(2) it does not consider the time value of net inflows.

The DPP method adjusts for the time value of cash flows while applying the conservative liquidity measure of the PB method (Brigham & Gapenski 1988).

20.2 Financing commercial aquaculture projects

This section of the chapter has been adapted from ABA (1995). Potential lenders, investors, and other financiers of aquaculture enterprises need a clear understanding of how much capital is needed and how it will be used. A logical business plan with realistic financial projections can facilitate that understanding. Along with evaluating the financial feasibility of a proposed enterprise, projected income (profit and loss), balance sheets and cash flow statements will be needed to forecast the initial ('start-up') and working capital needs of the enterprise. For existing aquaculture enterprises, these financial projections may be partially predicated on historical financial information and experience within the enterprise. If a new enterprise is being proposed, financial projections might be based upon financial information on similar aquaculture enterprises in a given geographic area and an economic analysis of experimental aquaculture research (Shang 1990). Sources of financial information may include universities, government agencies, trade associations, and business consulting companies with experience in the aquaculture industry, although Behrens & Hawranek (1991) caution against only using feasibility study data provided by '. . . suppliers of equipment or technology.'

Cash flow projections are critical in determining the short-term financing (operating capital) needs of an enterprise. Seasonal fluctuations in sales, such as only being able to harvest an aquaculture species for 6 months or less during a 12-month cycle, may cause cash shortages. In addition, a new aquaculture enterprise often takes at least 12 months before reaching the break-even point on a monthly basis. For aquaculture enterprises growing species that take less than 12 months to reach market size, such as freshwater prawns, there may still be lags in cash flows of 3 to 6 months before any positive cash flow is generated. In contrast, long-term financing is usually employed to finance fixed assets (e.g. construction of a processing facility) and permanent working capital. In any case, projected sales and expenses need to be realistic, and it is often wise to overestimate expenses. One simple forecasting technique is to increase initial base case (normal) estimates for the first 12 months of projected expenses by 20 to 30%. Suggestions on financial forecasting for new aquaculture enterprises, plus common forecasting errors can be found in Rhodes (1991).

20.2.1 Types of financing

There are two general sources for starting or expanding a business enterprise – external and internal (owner) financing. Internal (owner) financing means starting or expanding an enterprise using the principal owners' personal funds or assets. In many situations it may be the only way to 'kick-start' a new enterprise. Typical sources of internal financing include using a portion of personal savings, using salary income from other members of a household or selling securities (e.g. stocks, bonds, etc.). Risking a significant amount of their own funds may be beneficial for the enterprise's founding owners in the following ways: (1) lower debt load risks for the enterprise; (2) reduced risk of diluting management control due to premature external financing by venture capitalists or other parties; and (3) general willingness of external financing sources to offer more desirable financing terms because the principal owners have confidently invested their own capital. For example, business research has shown that the likelihood of small business enterprises having financial difficulties in the first year increases as the percentage of the owner's personal funds decreases (Carter & Van Auken 1990). Consequently, some investors and lenders are not interested in risking funds they control on a new or existing enterprise unless the principal owners have a substantial vested interest in the enterprise.

As the name implies, external financing is capital secured outside of the company and its principal owners. External financing is available in two general forms, debt and equity capital. Debt capital is derived from an agreement obligating the borrower to repay its lender with interest, meaning the debtor will eventually repay the lender more money than initially borrowed. Debt capital (loans) are usually classified as short-term if they can be repaid within 12 months and long-term if repayment will take more than a year. Loans can be either unsecured or secured. Security is the collateral offered and accepted by a lender to assure repayment of a loan. The lender often has the option to seize the collateral and sell it to repay the loan if the borrower (debtor) defaults on the loan. In general, long-term loans are more likely to be secured than short-term loans. For example, equipment loans are often secured by a lien in favour of the lender against the equipment. External equity capital usually involves selling off a portion of the enterprise to outside investors. In essence, an equity investor becomes a business partner and usually has some control over how the enterprise operates.

The greatest advantage of debt financing, compared to outside equity financing, is that it usually allows the enterprise founders to maintain control over their business. In contrast, debt financing increases the risks that an enterprise may not be able to service its debt (i.e. interest and principal payments), especially during the early years of a new enterprise when expenses may be higher than projected. The most significant advantage of outside equity financing is that it does not normally create an initial obligation of repayment and therefore an infusion of equity capital will not be an immediate drain on the cash flow of the business. Again, the enterprise's founders ordinarily must share control of the business with outside equity investors; this is one of the greatest disadvantages of equity financing.

20.2.2 Sources of capital: an overview

There is a variety of debt financing sources from which to choose, especially if financing is being sought for a viable on-going business enterprise. Common sources include commercial banks, trade credit from suppliers, and various government loan programmes, which will be briefly discussed here. Although debt financing through various types of commercial banks is still common for small businesses, the perceived riskiness of aquaculture enterprises has caused many banks in the USA and some other countries to avoid lending to aquaculture enterprises, or to employ relatively stringent lending requirements. Trade credit is usually a very short-term 'loan', which is advanced in the form of deferred payments by a firm's key suppliers of goods and services. Trade credit comes in many forms and, unlike commercial bank loans, may be based on informal agreements with critical suppliers. For example, a feed supplier might allow a prawn farmer to defer payment on a feed purchase for 30 days or more after actually taking delivery. This type of credit needs to be evaluated carefully, especially if the supplier is charging substantially more for the equivalent product or service that can be purchased elsewhere more cheaply with immediate cash payment. Short-term operating loans from commercial lenders may be less expensive than trade credit. Features (e.g. eligibility, lending terms, etc.) of government loan programmes for aquaculture enterprises vary by country, and the details of these programmes are beyond the scope of this chapter. It is important to note that some programmes may have a large backlog of eligible applicants, so it may be wise to seek out private funding sources, as well, if time is of the essence.

Sources of equity-oriented capital include friends and family, private (informal) investors, and venture capital companies. The social norms and traditions associated with seeking and obtaining capital from friends and family (F&F) in different countries are definitely beyond the scope of this author. In the USA, a potential F&F financing source is probably best approached through a personal contact that treats the person as a potential business investor. The private investors may include F&F, but are usually business professionals who are interested in funding a new or existing business enterprise. These private investors, also known as 'angels', may be identified through 'networking' with attorneys (lawyers), accountants, and suppliers. It has been estimated that angels annually invest more than US$ 32 billion of equity in US small businesses.

Venture capital (VC) companies usually invest equity oriented capital in new and expanding companies. Venture capital companies differ from lenders because they are generally oriented towards rapid growth in the company they fund, while lenders are mainly concerned with stability. The chances of securing equity capital from VC companies are questionable. Rhodes (1996) reported on a survey of VC companies in the USA and Canada, which indicated that VC companies are probably not a viable source of start-up capital for new aquaculture enterprises; furthermore VC companies in the USA and Canada are generally not interested in aquaculture projects in other countries.

20.3 Commercial prawn farming: costs and profitability

As New (1995) pointed out, there are only a few published case studies of existing commercial operations, while much remains proprietary information. Therefore, published and unpublished data on the costs and returns related to commercial freshwater prawn farming in the following sections are often based upon small-scale experiments, demonstration projects, hypothetical prawn farming enterprises, and other sources in the public domain. In addition, information on economic data from the country with the largest farmed production of freshwater prawns, China, is lacking. The following review is further complicated by differences in the specific production situation (e.g. temperate zone growing season *versus* tropical climates), price sources, and critical production assumptions such as harvest sizes and yields. However, the following review should still serve to provide a beneficial synopsis of such published and unpublished information as exists. All monetary data have been converted into US dollars (US$), and cost comparisons of the different production stages (Tables 20.1–20.5) have been adjusted to 1997 US$.

20.3.1 Hatchery production

20.3.1.1 Investment costs

One of the first published comprehensive case studies of existing commercial hatcheries was prepared by Kloke & Potavos (1975) on two small-scale hatcheries near Bangkok, Thailand. Based upon 1973–1974 data, initial investment costs, excluding land and operating capital, were US$ 6550 and US$ 23 790 for hatcheries with an estimated annual capacity of 490 000 prawn postlarvae (PL) and 600 000 PL, respectively. Driven by the expansion of prawn grow-out farming in the 1970s, the demand for PL expanded rapidly in Thailand. For example, between 1978 and 1980, the estimated number of prawn hatcheries increased from 12 to 59 and output increased nearly 10-fold from 2.6 million PL in 1978 to an estimated 25.8 million in 1980 (Anonymous 1980). In addition to market demand, government hatcheries in Thailand also stimulated the expansion of commercial hatcheries (Chapter 5).

Initial investment in a hatchery by 1980 ranged from only US$ 920 for a small unit (450 000 PL/yr) to US$ 12 680 for a 'medium' unit (2.6 million PL/yr) and to an average of US$ 60 080 for a 'large' hatchery (5 million PL/yr). With expansion of the hatchery sector in Thailand, annual output to initial investment efficiencies improved. In 1973, the initial investment ratio to hatchery capacity ranged from about US$ 13 to nearly US$ 40/1000 PL/yr. By 1980, the initial investment to annual PL ratio had declined to the US$ 2 to US$ 12/1000 PL/yr range. Singholka (1982) noted that the largest commercial prawn hatchery in Thailand during 1979 had a potential annual output of 30 million PL and cost US$ 500 000 to construct. With improvements in flow-through hatchery systems (Chapter 5), the cost of a Thai hatchery capable of producing up to 50 million PL/yr had declined to US$ 10 000 in 1997 (Table 20.1).

Freshwater prawn hatcheries have always tended to be mostly 'backyard' in scale in Thailand. Suwannatos (1996) reported that the aggregated annual production of 50 backyard hatcheries in 1995, 600 to 800 million PL, was sufficient to stock 6400 ha of grow-out ponds. Sebastian (1990) projected the costs and returns of a backyard hatchery in India during 1989 with an output of about 2.1 million PL/yr and estimated the initial investment in equipment (i.e. excluding land and buildings) at US$ 4000. Based upon a study of four Indian freshwater prawn hatcheries, the average initial investment needed for a small-scale commercial hatchery with an annual capacity of 500 000 to 600 000 PL in 1989–1990 was estimated to be about US$ 12 340, with approximately 68% spent

Table 20.1 Examples of investment costs for freshwater prawn hatcheries, adjusted to 1997 US$, excluding the purchase of land unless otherwise specified.

Country	Output[a] (000)	Facility investment (US$)	Investment per 1000 PL (US$)	Source
India	200	4816	24.08	Sebastian (1990)[b]
Thailand	450	1366	3.03	Anonymous (1980)
Thailand	2600	18822	7.24	Anonymous (1980)
Brazil	4000	100000	25.00	Brazil 1997 unpubl. data
India	5000	111379	22.28	Sebastian (1990)[c]
Thailand	5000	89180	17.84	Anonymous (1980)
Costa Rica	6000	100000	16.67	Costa Rica 1997 unpubl. data
USA[d]	6300	96502	15.32	Fuller *et al.* (1992)[c]
Malaysia	10000	168127	16.81	Tiensongrusmee (1982)
India	20000	201000	10.05	India 1997 unpubl. data
Thailand	50000	10000	0.20	Thailand 1997 unpubl. data

Averages	Investment per 1000 PL (US$)
Asian hatcheries (>1 million PL/yr)	12.40
USA and Latin American hatcheries	18.99
All hatcheries	14.41

[a] Annual capacity of prawn postlarvae (PL) output (production) in thousands.
[b] Excluding cost of a building.
[c] Includes the purchase of land.
[d] Mississippi.

on fixed assets such as hatchery equipment (52%), construction of buildings (9%), and land (7%). Valenti *et al.* (1998) estimated that a backyard Brazilian recirculation hatchery with a production capacity up to 100000 PL/month (Chapter 6) would require an investment of only US$ 4000. These authors did not consider construction of buildings and land costs.

Projected costs and revenues of a small-scale government hatchery with an annual capacity of 10 million PL to be constructed in Malaysia in 1982 were reported by Tiensongrusmee (1982). The initial investment costs, excluding land, over a 3-year period (1982–1984) were US$ 130500 with the building, electrical generators, and water supply system constituting 24%, 33%, and 13%, respectively, of the total investment.

Studies on hatchery costs in continental USA include Leventos (1986) and Smith (1990). Fuller *et al.* (1992) estimated that a hatchery building would represent about 34% of the estimated total investment (US$ 84000) of a prawn hatchery constructed in Mississippi. Estimated costs of constructing hatcheries on island sites can be found in New *et al.* (1978) and Aquacop (1979).

20.3.1.2 Operating costs and profitability

Total operating costs for two small-scale hatcheries near Bangkok, Thailand in the 1973–1974 period, based upon outputs substantially lower than the hatchery capacity, ranged from US$ 14.8/1000 PL to US$ 30.4/1000 PL (Kloke & Potavos 1975). Labour costs constituted 22 to 31% of total operating cost. These authors projected a small hatchery operating at full capacity due to robust market demand could reduce total operating costs to about US$ US12/1000 PL. Total operating costs apparently declined as Thailand's hatchery sector expanded. By 1980, the average total operating cost of small-scale hatcheries was US$ 11.50/1000 PL, while medium- and large-scale hatcheries had total operating cost averages of US$ 9.00/1000 PL and US$ 10/1000 PL, respectively.

The annual labour cost for a large Thailand (30 million PL/yr) hatchery was about US$ 27000, which included employment of a manager, three biologists, and a '. . . number of workers . . .' (Singholka 1982). The PL sold by private hatcheries in Thailand during 1979 were in the US$ 17 to US$ 37/1000 PL range, but by 1981 had decreased to US$ 12.50/1000 PL. This decline apparently shifted some prawn farmers from producing PL in their small-scale hatcheries to buying PL from others. Production costs probably continued to decline markedly during the 1980s because New (1990) noted that PL selling prices in 1989 ranged from only US$ 1.40 to US$ 4.00/1000 PL. This was mostly due to improved hatchery production efficiencies but there may have been an overexpansion of the hatchery capacity in Thailand, since prices for 20- to 30-day PL by 1999 had fallen to US$ 1.25/1000 (M. New, pers. comm. 1999), the same price reported by New (1995) for 1993.

Based upon a projected output of 10 million PL in the third year of operation, the annual production cost including depreciation was projected to be about US$ 9.00/1000 PL for a government hatchery in Malaysia during 1982 (Tiensongrusmee 1982). Projected gross revenues were US$ 214 600 based upon expected PL selling price (US$ 21.50/1000 PL), which would result in a net profit (before taxes) of US$ 124 700. For four hatcheries in India, average allocated total production costs per hatchery run (cycle) were reported to be US$ 5.50/1000 PL by Sebastian (1990), which included labour (24%), feed (19%), and utility expenses (5%) plus fixed costs such as interest payments (19%) and management salaries (17%).

The location of hatcheries relative to feed and seawater sources may influence operating costs. In Thailand, coastal hatcheries had production costs some US$ 2.00 to 2.50/1000 PL lower than inland hatcheries transporting seawater (Anonymous 1980). Truong (1991) reported that the operating costs of small-scale freshwater prawn hatcheries in the Mekong delta of Vietnam in 1990 were US$ 0.6/1000 PL and US$ 1.15/1000 PL for a coastal and an inland hatchery, respectively. The coastal hatchery operating costs were lowered due to the availability of inexpensive *Artemia* and the dependency of the inland hatchery on transported saltwater.

In the USA, researchers have attempted to analyse factors influencing the lack of expansion in the US hatchery sector, especially with regard to supporting a domestic grow-out farming industry in the continental USA. Hagood & Willis (1976) believed that the production cost of prawn PL would not be a constraint to US grow-out prawn farming. However, Bauer *et al.* (1983) and Liao & Smith (1983) indicated that the commercial price of freshwater prawn PL and juveniles was a major constraint to the development of commercial prawn farming in the continental USA. Moreover, Fuller *et al.* (1992) observed that the break-even price (about US$ 7.90/1000 PL) for a commercial hatchery producing 6.3 million PL/yr was '. . . considerably lower . . .' than advertised commercial PL prices (*ca.* 1991) of US$ 20 to US$ 50/1000 PL. These authors qualified their observation by noting that marketing and transportation costs were not considered in their hatchery cost estimates.

The expansion of the prawn hatchery sector, and the possibility of declining PL prices in the continental USA, has apparently been constrained by the relatively seasonal and inconsistent commercial grow-out demand for prawn PL or juveniles compared to other countries such as Thailand. Preferences to invest in US marine shrimp farming (Hopkins 1991; Chamberlain 1991), not prawn farming, during the 1980s may have also competed for investment dollars from financiers interested in US aquaculture opportunities.

A simple comparison of variable costs for a marine (penaeid) shrimp hatchery in the Philippines during 1992 (Shang *et al.* 1998) indicated that labour costs (excluding sales commissions) ranged between 25 and 28% of total variable costs. Other factors being equal (e.g. trends in labour costs between Thailand *versus* the Philippines), it appears that commercially producing marine shrimp PL may be more labour intensive than freshwater prawn PL production. The purchase of marine shrimp broodstock and nauplii represented 22 to 26% of total production cost of the small- to large-scale penaeid hatcheries (Shang *et al.* 1998). Fuller *et al.* (1992) estimated that freshwater prawn broodstock purchase and care in the USA would only represent about 6% of total production costs. Unlike marine shrimp broodstock, freshwater prawn broodstock can apparently be purchased at 'normal' market prices in Thailand (New 1996) and other countries, or berried females are readily available from integrated grow-out ponds at no cost (M. New, pers. comm. 1999). A study of hatcheries in India using 1989–1990 data (Raju & Nair 1992) revealed that an average of 1202 person-days of employment were generated per hatchery and the initial investment could apparently be paid back in the first year of operation, assuming there were five to eight successful hatchery runs and a PL selling price of US$ 18.50/1000 PL.

One of the most comprehensive published studies (Fuller *et al.* 1992) on hatchery profitability was based upon a hypothetical facility in a minor prawn producing country, the USA. Their price and PL survival sensitivity analysis revealed that positive net returns for survival rates of 70% occur when the FOB (free on board) selling price is US$ 10/1000 PL (*ca.* 1990) or higher. At an 80% survival rate and a selling price of US$ 14/1000 PL, the price (benefit) to cost ratio is 1.79. It is interesting to note that Shang *et al.* (1998) reported the 'benefit/cost ratio' of a medium-scale marine shrimp hatchery in the Philippines during 1992 to be similar, 1.87.

At full capacity, Kloke & Potavos (1975) projected net revenues per 1000 PL to be US$ 15.60 to 23.10, based upon an average selling price of US$ 35/1000 PL for two small-scale hatcheries in Thailand during 1974. The limited market demand for PL in 1974 was considered a major constraint to financial success because neither hatchery could operate near full capacity. The authors concluded that PL market demand should '. . . cease to be a problem . . .' once grow-out culture of freshwater prawns expanded in Thailand. This has, in fact, occurred.

Based upon a 1980 selling price of US$ 16.25/1000 PL, surveyed hatcheries in Thailand had annual profits ranging from US$ 4.85/1000 PL for small hatcheries to US$ 7.53/1000 PL for medium hatcheries and to US$ 7.40/1000 PL for large hatcheries (Anonymous 1980). The small hatcheries in 1980 had the highest rate of return (236%), mainly due to their small initial investment, followed by medium units (154%), and large (62%) hatcheries. Given these high returns, initial hatchery investment could be paid off within the second year of operation or sooner. The higher rate of return of the small hatcheries may also account for the expansion in the number of backyard hatcheries in Thailand, which has been noted in Chapter 5.

Sebastian (1990) projected net annual revenues of US$ 17.5/1000 PL, based upon a PL selling price of US$ 18.50 and total operating cost of about US$ 1/1000 PL for a 2.1 million PL/yr small-scale hatchery in India. Projected sales of only 3900 PL (Sebastian 1990) would be the break-even point for recovery of the allocated annual fixed costs. In a comparative economic analysis of public and private sector hatcheries in India, investigators (Raju & Nair 1992) found that the public hatcheries were less cost-effective, even though the average PL survival rate of the public hatcheries was higher (62%) than those in the private sector (39%). Based on a 40% PL survival rate, the estimated rate of return (ROR) on the initial hatchery investment in public hatcheries was less than 8% while the private hatcheries' ROR was on average about 23%. Net profits of 12% from a pilot project in the state of Kerala, India, were reported by Jacob & George (1993) for a pilot-scale commercial prawn hatchery producing 125 000 PL in its first year, 1991–1992.

Angell (1992) reported that a small-scale hatchery in Bangladesh using a recirculation system could yield 12 to 17 PL/L. In order to generate an adequate return on investment (ROI), the Bangladeshi hatchery would need to generate five PL batches (cycles) per annum. Angell (1994) projected that an IRR of 22% could be generated based on a hatchery yield of 15 PL/L, three cycles per annum, and a selling price range of US$ 12.5 to 25.0/1000. At a yield of 20 PL/L, the projected IRR increased to 41%.

20.3.1.3 Comparative cost analysis

The total investment costs of freshwater prawn hatchery facilities obviously increase with annual output capacity. A comparison of hatchery investment costs from 1990s sources, adjusted to 1997 US$ (Table 20.1), indicates that investment cost per 1000 PL of annual output capacity does appear to generally decline as the overall capacity of the hatchery increases (Fig. 20.1). Lee & Wickins (1992) also noted that investment per monthly capacity *versus* monthly output in millions of PL decreased with the output capacity of the hatchery when analysing marine shrimp and prawn hatcheries (mainly large marine shrimp hatcheries capable of producing over 100 million annually). A regional comparison of prawn hatcheries suggests that the average investment per output of the Asian hatcheries, US$ 12.40/1000 PL, was smaller than the average, US$ 18.99/1000 PL, for hatchery investment in the Americas (Table 20.1). This difference is due to the two hatchery examples listed with the highest capacity being located in Asia. In any case, those planning to construct a prawn hatchery may need to plan an investment as high as US$ 25/1000 PL (1997 dollars) of capacity.

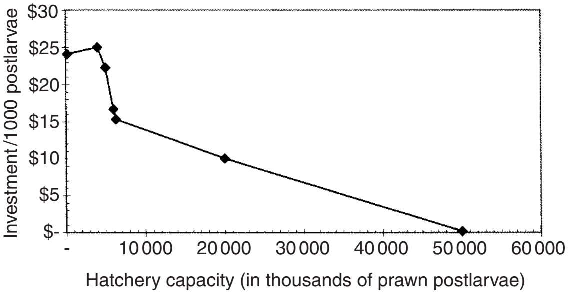

Fig. 20.1 Freshwater prawn hatchery capacity *versus* investment cost per thousand postlarvae (PL) of output based upon hatchery costs reported in the 1990s (see Table 20.1). Note: the investment cost per 1000 PL for a 50 000 PL capacity hatchery is US$ 0.20, which appears as zero on the scale used in this figure

As might be expected, the annual operating cost of the two hatchery examples with an annual capacity of over 10 million PL was substantially lower than the operating cost of hatcheries with a smaller capacity (Table 20.2). A comparison of the average labour cost percentages of hatcheries with an annual capacity of 10 million PL or less in Asia (Fig. 20.2) *versus* the Americas (Fig. 20.3) indicates that the hatchery labour cost in American hatcheries may have been much higher than the labour cost for Asian hatcheries during the 1990s. This difference is probably due to generally lower labour wage rates in the Asian countries listed, compared to the countries in the Americas.

20.3.2 Nursery production

A nursery phase may be employed to 'head start' juvenile prawns before stocking them in the grow-out system. Variable operating costs of a nursery

Table 20.2 Examples of freshwater prawn hatchery annual operating costs per thousand postlarvae (PL) in 1997 US$, with selected cost categories as percentages of total annual operating costs.

Country	Output[a] (000)	Cost per 1000 PL (US$)	% of operating costs				Source
			Labour	Feed	Energy	Other	
India	200	6.74	32	19	5	44	Sebastian (1990)
Thailand	450	17.07	15	39	10	36	Anonymous (1980)
Tahiti	1 500	12.29	48	13	9	30	Aquacop (1979)
Thailand	2 600	13.36	12	21	5	62	Anonymous (1980)
Brazil	4 000	10.00	30	50	20	0	Brazil 1997 unpubl. data
Thailand	5 000	14.84	9	19	5	67	Anonymous (1980)
Costa Rica	6 000	15.00	35	26	12	27	Costa Rica 1997 unpubl. data
USA[b]	6 300	9.13	51	20	9	20	Fuller *et al.* (1992)
Malaysia	10 000	11.63	41	24	3	32	Tiensongrusmee (1983)
India	20 000	5.00	16	53	4	27	India 1997 unpubl. data
Thailand	50 000	1.08	6	65	2	27	Thailand 1997 unpubl. data

Averages	Cost per 1000 PL (US$)	% of operating costs			
		Labour	Feed	Energy	Other
Asian hatcheries[c]	12.73	22	24	6	48
American hatcheries	11.38	39	32	14	15
All hatcheries	10.56	27	32	7	34

[a] Reported annual capacity of prawn PL output in thousands.
[b] Mississippi.
[c] Capacity of 10 million PL or less.

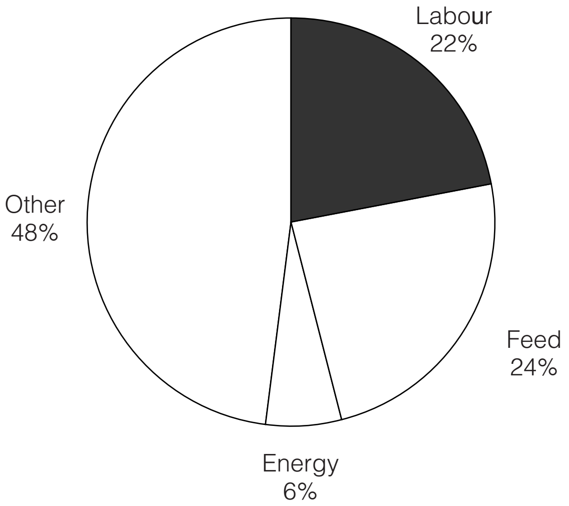

Fig. 20.2 Average operating cost percentages for Asian freshwater prawn hatcheries with a capacity of 10 million postlarvae (PL) or less (see Table 20.2)

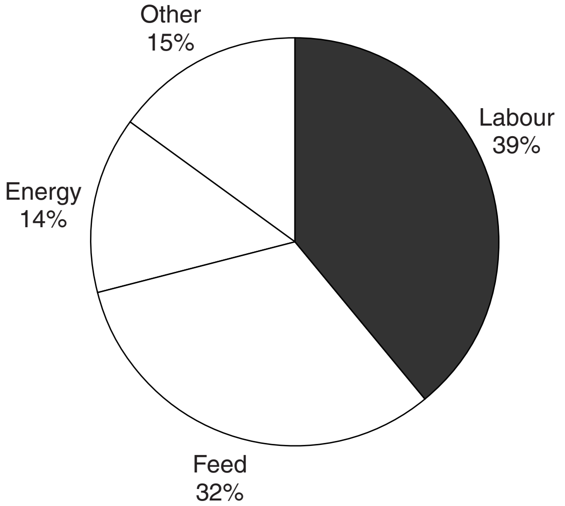

Fig. 20.3 Average operating cost percentages for American freshwater prawn hatcheries (see Table 20.2)

phase using outdoor earthen ponds in Malaysia during 1981 and 1982 were reported by Tiensongrusmee (1983). The total variable costs were US$ 1913 for a pond area of 2000 m^2 (US$ 9565/ha) when initially stocked with 30 PL/m^2 and reared in the nursery ponds for 60 days. As might be expected, the PL cost (81% of the total) was the major variable cost, followed by labour expense (4%). The variable cost of the nursery juveniles was US$ 45.55/1000; the author did not provide details on the weight of harvested juveniles. Based upon experimental research in the Southeast of Brazil's State of São Paulo, Faria & Valenti (1995b) estimated that indoor nursery systems had an operating cost ranging from US$ 89/1000 to US$ 106/1000 juveniles, while outdoor nursery systems ranged from US$ 34/1000 to US$ 50/1000 juveniles. Juveniles were reared for about 60 days during the winter season. These authors concluded that outdoor nursery systems employing earthen ponds were more desirable than indoor winter nursery techniques because of the lower costs per juvenile.

Based on unpublished 1997 data, investment costs for juvenile production facilities integrated with grow-out farms in Latin America were US$ 40 000 and US$ 50 000 for producing 4 million and 2 million 2 g juveniles per year, respectively. Total annual operating costs for producing 2 g juvenile prawns were US$ 6/1000 and US$ 10/1000 for facilities in Brazil and Costa Rica, respectively (Table 20.3). The production costs for 10 g juveniles in Thailand (US$ 50/1000 juveniles) were over eight times higher than the estimated cost in Brazil (US$ 6/1000) for producing 2 g juveniles. Feed expenses represented 40% or more of nursery production costs, while labour cost percentages in the Latin American countries were higher than those for the two Asian countries.

20.3.3 Grow-out production

20.3.3.1 Costs and profitability

Various economic feasibility studies have been published on freshwater prawn grow-out farming in Asia, but there have been very few published case studies on actual economic performance. Shang (1982) compared the costs and returns of Thai and Hawaiian prawn farms and found that the initial investment in Hawaii during 1980, which ranged from approximately US$ 8200 to US$ 17 200 per 0.4 ha pond depending on the farm's overall size, was about 2.5 to 8.9 times higher than in Thailand. The cost in Thailand during 1980 increased from

Table 20.3 Examples of freshwater prawn nursery annual operating costs per thousand juveniles in 1997 US$, with selected cost categories as percentages of total annual operating costs.

			% of operating costs				
Country	Output (000)	Cost per 1000 (US$)	Labour	Feed	Energy	Other	Source
Thailand	1000	50.00	7	80	13	0	Thailand 1997 unpubl. data
Brazil	2000	6.00	25	40	25	10	Brazil 1997 unpubl. data
Costa Rica	4000	10.00	14	63	11	12	Costa Rica 1997 unpubl. data
Malaysia	nr	59.26	4	3	0	93	Tiensongrusmee (1983)[a]

[a] 'Other' includes the cost of postlarvae (PL) while other operations may not have included PL costs in their estimates.
nr = not reported.

US$ 1928 for a single-pond 0.4 ha farm to US$ 3278 per 0.4 ha pond for an 8 ha farm. Shang (1982) attributed this increase in cost per unit of pond (0.4 ha) to the larger quantities of equipment used and the generally better pond construction as Thai farms became larger. Since Hawaiian farms had a higher initial investment than Thai farms, depreciation and interest payments, on average, were 3 times and 12 times higher, respectively, than in Thailand. Comparing annual operating cost percentages of 4 ha farms, labour (34%) represented the highest cost component in Hawaii, while expenditures for PL (23%) represented the highest category for Thai farms. In 1980, the cost of labour per kg of marketable prawn for Hawaiian farms was 6.8 times higher than in Thailand. Although the yields per 0.4 ha were higher in Hawaii (800 kg) compared to Thailand (400 kg) in 1980, the production cost in Thailand ranged from US$ 2.95/kg to US$ 4.50/kg depending on farm size, and was much lower than in Hawaii (which ranged from US$ 8.6 to US$ 10.50). The average annual operating cost per kg of prawns in Hawaii was about 2.7 times higher than in Thailand. Moreover, the ex-pond prices of prawns in Hawaii during 1980 (about US$ 8.80/kg) were only 1.2 times higher than Thailand (US$ 7.30/kg). Shang (1982) concluded that all of the three farm sizes in Thailand were making '. . . good profit . . .' (i.e. net revenues of US$ 2.50/kg or more). In contrast, 0.4 ha and 4 ha farms in Hawaii had negative net revenues and an 8 ha farm was only breaking even in 1980.

Shang (1982) indicated that the production costs of 8 ha farms in Hawaii (US$ 8.61/kg) were almost twice the estimated cost in Thailand (US$ 4.50/kg). The Thai farms received lower prices and had lower average yields than Hawaiian farms, but Thai farms were still more profitable because of lower production costs. It is interesting to note that Shang (1981a) also did a comparison of estimated production costs of extensive marine shrimp farming in Mexico and concluded that freshwater prawn culture had lower costs and would yield a slightly higher net profit than marine shrimp farming.

Based upon experimental trials in Sri Lanka, Hettlarachchi & Kularatne (1988) estimated gross revenues of US$ 1490 for small 0.1 ha ponds at a total operating cost of US$ 460 per pond, resulting in net revenues of US$ 1030, assuming two crops were produced per year. Assuming hatcheries could be developed, they recommended prawn farming to be developed in rural areas, especially where freshwater fish ponds were already established. These authors believed that prawns would be more profitable than fish culture because prawn market prices were generally higher than fish prices in Sri Lanka. Unpublished 1997 data on small prawn farms (1.5–7 ha) in the State of Tamil Nadu, India, indicated an initial investment cost of about US$ 395/ha and operating costs of US$ 2.92/kg resulting in an average net profit of approximately US$ 3.33/kg for an ex-pond selling price of US$ 6.25/kg (N. Sukumaran, J. Christopher & R. Neeraja, pers. comm. 1998). Annual yields per ha ranged from 1350 to 6300 kg, with feed (47%) and seed (42%) constituting most of the operating costs.

Sadek & El-Gayar (1995) estimated production costs in Egypt from experimental trials in which freshwater prawns were cultured in brackishwater earthen ponds. Total production costs, based upon an initial stocking density of $2/m^2$ (0.7–1.0 g prawns) and an average yield of 655 kg/ha, were estimated to be US$ 17510/ha. Prawn juvenile costs, at US$ 60.61/1000, represented 64% of the variable costs (i.e. juveniles, feed, and electricity) or about 7% of the total per hectare production costs. In contrast, labour costs were only 1% of total production costs. Net income was estimated to be a negative US$ 12657/ha, but these authors believed that higher production was feasible if stocking rates were increased from 7/m^2 to 10/m^2. However, an extrapolation from the experimental production and cost data given by Sadek & El-Gayar (1995), based on a stocking density of 10/m^2, indicated that higher yields would still not make brackishwater culture profitable.

Hsieh *et al.* (1989) estimated that the production costs in Taiwan's freshwater prawn farming industry ranged from US$ 3.80/kg to US$ 5.70/kg, with wholesale prawn prices ranging from US$ 11.30/kg to US$ 15.00/kg depending upon the season. These costs exclude land cost because farming land is usually not sold, but passed down through generations. Based upon annual yields of 4000 kg/ha to 5000 kg/ha, a successful farm could expect a 'net income' of about US$ 37800/ha in Taiwan during the 1980s. It was not clear from Hsieh *et al.* (1989) if this income was before or after deducting for family labour costs.

Lo & Hwang (1994) investigated the structure of Taiwan's aquaculture industry, including the income and costs of freshwater prawn farming during 1992 and found that prawn farming had the third highest cost per hectare among nine aquaculture species. Survey results indicated that total annual operating costs were about US$ 45300/ha with labour and feed/fertiliser constituting 22 and 41%, respectively, of total costs. These authors estimated that the average net revenues/ha were negative (US$ 10200/ha) in 1992 and believed that better disease control in prawn production would improve profits.

Liao (1996) found that only small prawn farms (less than 1 ha) in Taiwan during 1993 were unprofitable while medium (1–2 ha) and large prawn farms (>2 ha) had average net returns of US$ 3390/ha and US$ 3610/ha, respectively. The larger farms were able to generate more revenue per unit of output probably due to economies of scale. A production function analysis indicated that prawn farming profits in Taiwan could be increased by the expansion of the farm size and more intense use of labour, but a conclusion of this study was that high production costs were likely to deter additional investment in the industry. Chien (1992) cited several factors which constrained the further large-scale expansion of freshwater prawn production in Taiwan, including the inability to grow prawns greater than 30 g in 5 months and the substitution of lower-priced marine prawns for freshwater prawns. Consequently, freshwater prawn market conditions plus relatively high production costs have probably limited prawn farming profitability in Taiwan. Moreover, retarded growth, inbreeding, overuse of underground water resources and high production costs have also contributed substantially to a decline in national production (see Chapter 17).

In Latin America and the Caribbean, several studies has been done on the economic feasibility of commercial grow-out prawn farming. New *et al.* (1978) investigated the technical and economic feasibility of developing commercial freshwater prawn farming in the Windward Island of Dominica, based upon a government-controlled and subsidised prawn hatchery. Estimated pond construction costs on a 1:50 land gradient without a gravity freshwater supply, ranged from US$ 11132/ha to US$ 19151/ha for 4 ha to 0.8 ha farms, respectively. Based upon 2800 kg/ha/yr and an ex-pond price of US$ 4.90/kg, these authors concluded that a Dominican farm could be profitable, assuming that land purchase was not needed. A 4 ha farm, depending upon land gradient and water supply, could pay back the initial investment in 5 years or less. MacMichael *et al.* (1992), who reviewed 2 years of trials in El Salvador utilising size grading for pond stocking and above-ground, high-density concrete nurseries, reported gross revenues of US$ 24864/ha/yr based upon a yield of 2188 kg/ha/yr.

Valenti (1992, 1993) estimated that the total production costs in Brazil, a country with one of the highest national production levels in the western hemisphere, ranged between US$ 3.00/kg and US$ 5.00/kg during the early 1990s. Based upon a domestic market price of at least US$ 5/kg (Valenti 1993), net revenues would have been approximately US$ 2/kg during this time period for Brazilian farms with production costs near US$ 3/kg. Experimental trials by Valenti & Sampaio (1996) have shown that net revenues are maximised at US$ 912/ha (403/kg/ha) with an initial post-larval stocking density of 1.5/m^2 in the 8 months of grow-out. These results are consistent with lowering stocking densities in order to increase overall prawn size rather than aggregate yield. Moreover, applied research by Faria & Valenti (1995a) demonstrated that 0.3 g juvenile prawns stocked at experimental densities of $4/m^2$ yielded net revenues equivalent to US$ 3277/ha. When density increased to $5/m^2$, net revenues declined substantially to just US$ 831/ha. The higher net revenue at the lower density was mainly due to much higher prices for the larger prawns. Trials performed by Valenti (1989) showed that profitability depends on stocking density in low-technology semi-intensive culture (see Chapter 10). Excluding fixed costs, net revenue could attain US$ 9047/ha/yr, when stocking $4\,PL/m^2$. Stocking 12 to $20\,PL/m^2$ was not profitable. This analysis, which did not consider fixed costs, was based on current prices during the middle 1980s in Brazil, when large prawns achieved a high price.

In the continental USA, several studies have been conducted to evaluate the financial feasibility of grow-out systems, especially in South Carolina (Roberts & Bauer 1978; Sandifer *et al.* 1982; Bauer *et al.* 1983). Bauer *et al.* (1983) estimated there would be negative net revenues for a 4 ha South Carolina grow-out farm regardless of the seed stock prices, stocking strategies (e.g. mixture of PL and juveniles) and possible marketing alternatives, if investment costs included the construction of new ponds and water supply. Even when existing facilities (i.e. pond construction and well drilling costs were excluded) could be utilised, estimated net revenues were often negative when using either a mixture of PL and juveniles or only juveniles. Positive net revenues were partially contingent on the development of market segments for whole ('heads-on') prawns (Sandifer *et al.* 1982; Bauer *et al.* 1983). The lack of seed or its high unit cost were also identified as major problems confronting the development of prawn farming in South Carolina (Liao & Smith 1983).

Based upon 7 years of experimental data and heads-off marine shrimp price trends, Montanez *et al.* (1992) estimated that net revenues for a 4 ha freshwater prawn farm in the hill area of Mississippi, USA, during 1991, would also be negative. Net revenues associated with size-grading strategies were less negative than most of the ungraded strategies at similar stocking densities. The estimated investment in the 'synthesised' or hypothetical Mississippi prawn farm used in their analysis was US$ 93 041 or US$ 23 260/ha. Depending upon stocking strategies, total annual operating costs were estimated to range between US$ 2714/ha and US$ 9987/ha. A sensitivity analysis of size-grading strategies showed positive net revenues if an average whole prawn wholesale price of US$ 3.50 was assumed. As in South Carolina, this assumption was predicated on a robust domestic niche market for whole prawns being sold directly to consumers and restaurants, an assumption that still remains questionable for the continental USA.

An enterprise budget analysis, based upon small commercial 0.4 ha grow-out facilities on existing agricultural farms in Kentucky, indicates the potential for modest profits from prawn farming in continental USA (Woods *et al.* 1998). Based upon an initial investment of about US$ 7600 for a 0.4 ha pond, these authors projected a net profit of US$ 2700 after a 100-day grow-out period when stocking juvenile prawns. Their enterprise budget projections were based upon ex-pond prices paid by live-haul wholesale distributors. Like others analysing the commercial feasibility of US prawn culture (Montanez *et al.* 1992), Woods *et al.* (1998) were concerned about market prices and cautioned US aquaculturists that '. . . a thorough investigation of the marketing alternatives should be made even before pond construction.'

There were several commercial efforts towards development of freshwater prawn farming in Australia (Anonymous 1976) some two decades ago. Pashen (1984) adapted data from Hawaii, mainly data from Shang (1981b), to determine the economic feasibility of a hypothetical 8 ha prawn farm in Queensland. The estimated initial investment in 1983 was US$ 210 000, with a total grow-out annual production cost of US$ 8.13/kg. Pashen (1984) assumed that freshwater prawn producers would need to compete against marine shrimp species, but prawn farms would not be profitable because the Australian wholesale market price for marine shrimp species was generally less than the projected break-even price (US$ 8.13/kg) for an 8 ha prawn farm. The outlook for the development of the freshwater prawn farming industry is not very promising in Australia (Treadwell *et al.* 1992) because of unfavourable market conditions (e.g. lack of developed domestic market segments for prawns, competition from imported prawn and marine shrimp products) and lower yields (i.e. higher costs per kg) compared to marine shrimp farming. This analysis is consistent with trends in the USA, where perhaps costs and market conditions are similar to those in Australia. Currently (1999), there is no freshwater prawn farming in Australia (Chapter 17).

Vertical integration in the private sector is defined as a business that combines two or more sequential stages of production and marketing distribution in the same overall organisation or control. For aquaculture enterprises, lowering costs could be a major objective of vertical integration if one or more of the following benefits could occur from integration:

(1) optimising functional efficiencies such as hatchery and marketing functions;
(2) optimising the use of the firm's human resources; and
(3) improved co-ordination of critical production and distribution stages (Jolly & Clonts 1993).

There was some evidence that vertical integration of prawn hatchery and grow-out operations may lower operating costs. A case study of an integrated hatchery and grow-out pond operation in Thailand indicated that the 1980 cost of PL production was at least US$ 3.00/1000 PL lower than those hatcheries with similar capacity but having no grow-out pond operation (Anonymous 1980). In addition, the cost of production for the integrated grow-out operation (US$ 2.65/kg) was lower than those grow-out farms without their own hatcheries (US$ 2.95–4.50/kg). Although the authors (Anonymous 1980) did not discuss the possible reasons for the differences, it is interesting to note that the cost of PL per rai (0.16 ha) for the grow-out operation in the integrated farm comprised 8% of total operating costs while the cost of PL for regular grow-out farms in the same size range, 2.4 to 6.4 ha, represented 23%. Consequently, the lower costs associated with the grow-out operation in the integrated farm may have been due to the internal use of PL from the farm's own hatchery. Many freshwater prawn grow-out farms in Thailand now rear their own PL on inland sites, and often exhibit further vertical integration by making their own aquafeeds (M. New, pers. comm. 1999).

20.3.3.2 Comparative cost analysis

The adjusted aggregate investment costs in 1997 dollars of grow-out facilities, as in the case of hatcheries, increases with annual output capacity (Table 20.4). Excluding US facilities, investment costs per ha averaged about US$ 6600/ha and ranged from US$ 400 in India to US$ 12 164 in Thailand. In contrast, the average investment cost per ha for US facilities (US$ 32 800) was five times the average for other countries. The higher initial cost of US facilities is probably due to more complex design (Shang 1982) and higher construction labour wages, compared to other countries such as Thailand. Within the USA, the cost of pond construction in Hawaii was higher than the cost in continental USA (Table 20.4) because pond construction cost, which is mainly influenced by the contractual costs for earthmoving, was substantially higher in Hawaii.

Total annual operating costs ranged from US$ 1.85/kg/yr for government grow-out demonstration ponds in Pakistan to a high of US$ 15.59/kg/yr for a small, commercial 0.4 ha facility in Hawaii (Table 20.5). Input factors influencing this increase include the feeding and stocking protocols needed for higher yields. Overall, seed and feed cost averaged 20 and 30%, respectively, (50% combined) of total annual operating costs. Grow-out operations with labour costs comprising more than 11% of total operating costs had total operating costs averaging US$ 9.45/kg/yr while those with labour percentages under 11% averaged US$ 3.71/kg/yr. Except for Taiwan, grow-out operations with labour percentages less than 12% were in Asia. Lower wage rates in these countries compared to Taiwan and the Americas could have contributed to the lower total operating costs. It is also possible that labour costs were underestimated for prawn farming operations in Asia involving small family enterprises (Lee & Wickins 1992).

A comparison of operating cost percentages of intensive freshwater prawn and marine shrimp farming (Figs 20.4 and 20.5) indicates that the labour cost percentage for a Taiwanese prawn farm was about fives times the labour cost percentage for a Thai marine shrimp farm. This would seem to support the view that labour costs are proportionately lower in Thailand for prawn farming compared to prawn or marine shrimp farming in the

Table 20.4 Examples of investment costs adjusted to 1997 US$ for freshwater prawn grow-out farms, excluding the purchase of land unless otherwise specified.

Country	Area (ha)[a]	Yield (kg/ha/yr)	Facility investment (US$)	Investment per ha[b] (US$)	Source
Brazil	10	3000	100 000	10 000	Brazil 1997 unpubl. data
Costa Rica	50	600	300 000	6 000	Costa Rica 1997 unpubl. data
India	4	3800	1 580	400	India 1997 unpubl. data[c]
Pakistan	2	1500	3 682	1 841	New (1996)
Thailand	0.8	1100	6 442	8 053	Anonymous (1980)[d]
Thailand	4	1125	29 687	7 422	Anonymous (1980)[d]
Thailand	8	1140	97 315	12 164	Shang (1982)
USA[e]	0.4	2270	25 492	63 731	Shang (1982)
USA[e]	4	2270	136 487	34 122	Shang (1982)
USA[e]	8	2270	241 209	30 151	Shang (1982)
USA[f]	0.4	1130	7 400	18 600	Woods *et al.* 1998
USA[g]	4	1000	106 428	26 607	Montanez *et al.* 1992[a]
USA[h]	4	1000	94 738	23 684	Bauer *et al.* 1983

Averages	Investment per ha[b] (US$)
USA grow-out facilities	32 816
Other countries	6 554
All countries	18 675

[a] Water surface area of grow-out facility.
[b] Investment cost per ha of water grow-out surface area.
[c] N. Sukumaran, J. Christopher & R. Neeraja, pers. comm. 1998.
[d] Investment cost includes the purchase of land.
[e] Hawaii.
[f] Kentucky.
[g] Mississippi.
[h] South Carolina.

USA and Taiwan. For example, Rhodes *et al.* (1995) estimated that labour costs would represent 19% of total costs for an intensive marine shrimp farm in South Carolina, USA. The feed cost percentage (Fig. 20.5) for an intensive marine shrimp in Thailand (45%) was about the same as the freshwater prawn feed cost percentage (Fig. 20.4) in Taiwan (41%). These high percentages for feed costs only emphasised the need for cost-effective feeding protocols. Seed (PL) cost percentages for prawn farming in Taiwan (9%) (Fig. 20.4) were just 5 percentage points lower than the seed cost percentage for a Thai marine shrimp farm (Fig. 20.5). For both species, the major cost components of operating a farm are feed and seed, which account for 50% or more of operating expenditures.

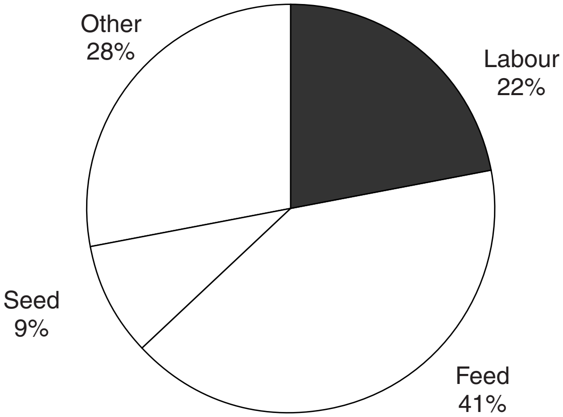

Fig. 20.4 Operating cost percentages for a 2 ha freshwater prawn farm in Taiwan. (Source: adapted from Lo & Hwang, 1994.)

Table 20.5 Examples of freshwater prawn grow-out annual operating costs per kg in 1997 US$, with selected cost categories as percentages of total annual operating costs, listed in ascending proportion of labour costs.

			% of operating costs				
Country	Area (ha)[a]	Cost per kg/yr (US$)	Labour	Feed	Seed	Other	Source
India	4	2.90	1	47	42	10	India 1997 unpubl. data[b]
Sri Lanka	0.1	1.96	5	45	20	30	Hettiarachi & Kularatne (1988)
Thailand	nr	2.40	6	44	44	6	Thailand 1997 unpubl. data
Thailand	8	6.68	7	24	27	42	Shang (1982)
Malaysia	nr	5.78	9	53	33	5	Sebastian *et al.* (1993)
Pakistan	2	1.85	10	24	27	39	New (1996)
Thailand	4	4.38	10	21	23	46	Anonymous (1980)
USA[c]	0.4	15.59	12	17	5	66	Shang (1982)
USA[d]	4	7.51	12	5	22	61	Bauer *et al.* (1983)
USA[e]	0.4	8.83	13	14	39	34	Woods *et al.* 1998[f]
USA[g]	4	4.46	16	27	23	34	Montanez *et al.* (1992)
Thailand	0.8	5.94	20	24	15	41	Anonymous 1980
Taiwan	2	9.60	22	41	9	28	Lo & Hwang 1994
Costa Rica	50	9.50	25	35	nr	40	Costa Rica 1997 unpubl. data
USA[c]	8	12.78	27	21	7	45	Shang 1982
Brazil	10	5.00	30	40	nr	30	Brazil 1997 unpubl. data
USA[c]	4	15.26	33	18	6	43	Shang 1982

		% of operating costs			
Averages	Cost per kg/yr (US$)	Labour	Feed	Seed	Other
Labour <11%	3.71	7	37	31	25
Labour >11%	9.45	21	24	13	42
All operations	7.08	15	30	20	35

[a] Water surface area of the grow-out facility.
[b] N. Sukumaran, J. Christopher & R. Neeraja, pers. comm. 1998.
[c] Hawaii.
[d] South Carolina.
[e] Kentucky.
[f] Seed costs based upon stocking of juvenile prawns.
[g] Mississippi.
nr = not reported. Operating costs percentages with nr were treated as zeros when calculating averages.

20.4 Polyculture and integration

The economics of polyculture have been reviewed by others (Shang 1990; Jolly & Clonts 1993) and draw upon theory related to production economics of two or more products by the same facility or plant, a multi-product firm (Mansfield 1991). Polyculture species groups can be generally categorised into the following three groups relevant to prawn polyculture: supplementary, complementary, and competitive. Supplementary species would have no positive or negative effect on each other. In contrast, complementary species would enhance the production of each other. Competitive species, as the name implies, are polyculture species that compete for the same resources in the system, such as food, and therefore reduce the output (e.g. size, yield, etc.) of the other. Researchers and commercial aquaculturists usually attempt to select polyculture groups that may have a complementary interaction (Jolly & Clonts 1993). It is also possible that species that are complementary at a certain density may become competitive at higher densities. Even for rice–fish farming, high rice seeding rates can have a negative effect on fish yields (Rothuis *et al.* 1999). Rouse *et al.* (1987) noted that

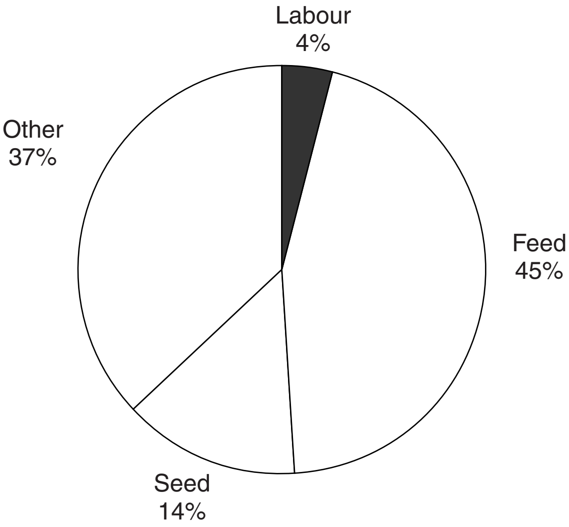

Fig. 20.5 Operating cost percentages for an intensive marine shrimp farm in Thailand. (Source: adapted from Shang *et al*., 1998.)

tilapia fry could reduce prawn survival in a prawn–tilapia polyculture system. Apparently the tilapia fry feed on post-larval prawns even though adult tilapia do not normally feed on small invertebrates. Mechanisms for interactions between prawn and other species are discussed in Chapter 12.

If complementary species can be identified and commercially cultured with prawns, polyculture net revenues could be higher than a prawn monoculture system. This assumes that incremental costs and other factors (e.g. harvesting logistics) associated with a polyculture technique do not offset the overall increase in gross revenues generated by the polyculture species. Sometimes the interest in polyculture techniques arises after a monoculture system has been constructed, and therefore polyculture is viewed as a strategy to 'squeeze' more profits out of an existing fixed investment. Other commercial reasons proposed by researchers for developing prawn polyculture include the following: (1) reducing marketing risks by diversifying products (Meriwether *et al.* 1984; Hsieh *et al.* 1989), (2) reducing the risk of major crop losses due to algal blooms by improving ecological stability (Cohen *et al.* 1983), and (3) reducing overall operating costs by using manure instead of more expensive supplemental feeds (Malecha *et al.* 1981). Applied research on prawn polyculture grow-out techniques in temperate climates has also been rationalised based upon the limitations of increasing annual yields in a prawn monoculture system due to grow-out seasons of 7 months or less and the heterogeneous individual growth that occurs at high prawn stocking densities because of a single batch harvest in temperate climates (Wohlfarth *et al.* 1985).

Due to the commercial success of commercial catfish (*Ictalurus punctatus*) farming in the USA, researchers in the southeastern USA have been interested in prawn polyculture involving the channel catfish culture systems, usually earthen ponds. Huner *et al.* (1980) reported potential yields and gross revenues of 442 kg/ha (US$ 2652/ha) and 16 755 fingerlings/ha (US$ 838/ha) for prawns and catfish if stocked at low densities. They concluded that cultivation of catfish fingerlings and prawns may be biologically feasible, but additional experimentation would be needed to determine if it was commercially feasible. Cange *et al.* (1983) reported a demonstration of culturing food-size catfish with prawns and rice/crawfish (*Procambarus clarkii*) rotation. Based upon the projections of the experimental results, gross revenues were estimated to be US$ 4615/ha, with a net profit of US$ 1092/ha. Projected prawn and catfish sales were 39% and 33% of estimated gross revenues, respectively, with remaining revenue (28%) being derived from crawfish. The catfish and prawns were harvested by draining the pond, an atypical practice in the US catfish industry. The need to harvest prawns before the onset of colder autumn months and the usual catfish industry practice of seine harvesting of catfish fingerlings without draining the entire pond, are a major hindrance to the development of prawn–catfish polyculture in the USA (Avault 1996). Tilapia were also explored as a potential fish candidate of prawn polyculture in the USA. Experimentation in central Texas indicated that prawn–tilapia (*Oreochromis aureus*) polyculture had the potential of incrementally increasing gross profits by about US$ 1010/ha, even though prawn yields would be significantly decreased (Rouse & Stickney 1982). Based upon tilapia market prices of US$ 2.75/kg for individual fish averaging about 136 g, tilapia production, 1570 kg/ha, was projected to offset sales losses due to a 361 kg/ha decline in prawn output.

Since selective seine harvesting of prawns is normally practised in tropical areas (see Chapter 10), cage culture of tilapia has been considered as a possible prawn polyculture technique. Meriwether *et al.* (1984) experimented with the cage culture of red tilapia in prawn and marine shrimp ponds in Hawaii. Based upon a partial budget analysis, cage culture could incrementally increase gross annual profits by about US$ 2510/ha in prawn ponds and by US$ 5600/ha in brackishwater ponds used for marine shrimp. Projected gross profits from caged tilapia in the brackishwater ponds were higher than caged tilapia in freshwater ponds because overall tilapia growth was higher in brackishwater.

Fitzgerald (1988) analysed the comparative financial performance of a freshwater prawn polyculture farm involving three species of Chinese carps (*Hypophthalmichthys molitrix*, *Aristichthys nobilis* and *Ctenopharyngodon idella*) with other polyculture and monoculture farms in Guam. Monoculture of the Asian catfish, *Clarias batrachus*, had the highest IRR, 62%, and NPV, US$ 198 154/ha, compared to the freshwater prawn polyculture farm, a tilapia polyculture farm with catfish, a tilapia monoculture farm, and a milkfish monoculture farm. The freshwater prawn polyculture farm did have the second highest IRR, 38%, and moderate risk based upon the break-even point as a per cent of actual production. Although freshwater prawn polyculture weighted market (output) price per kg (US$ 15.44/kg) was 3.5 times greater than the market value for catfish monoculture, the net profit per ha of the catfish farm (US$ 40 786) was greater than the freshwater prawn polyculture farm by a factor of 3.7. The higher yield of the catfish farm, 26 904/ha, compared to only 2690/ha (71% prawns) for the freshwater prawn polyculture farm was obviously a major factor in offsetting the lower market value of the catfish.

Engle (1987) projected that freshwater prawn polyculture with fish species in Panama would be more profitable than monoculture of freshwater prawns. Prawn polyculture with tilapia (*Oreochromis niloticus*) and grass carp (*Ctenopharyngodon idella*) or colossoma (*Colossoma macropomum*) and carp had a projected 20-year IRR of 17 and 13%, respectively, while prawn monoculture had a 10% IRR. As in Guam (Fitzgerald 1988), the monoculture of tilapia, 9% IRR, was projected to be less profitable than prawn polyculture despite the higher tilapia yields per ha compared to freshwater prawn polyculture or monoculture.

The integration of prawn and rice culture or rice–prawn farming has become a common practice in the Mekong river delta of Vietnam (Hien *et al.* 1998) and is described in Chapter 12. Hung (1992) reported that rice–prawn farmers may average net revenues of about US$ 710/ha per crop of rice and prawns if they have prawn yields ranging between 100 and 300 kg/ha/crop. The contribution of prawn sales to net revenues of rice–prawn farming can be substantial. If prawn seed and feed costs are deducted from prawn sales, prawns still may incrementally increase net revenues per crop by about 80% compared to farming rice without prawns. Although extensive rice–prawn farming has the potential of increasing income levels of Vietnamese farmers, limited supplies of wild prawn seed or viable hatchery seed is apparently constraining further expansion of the industry (Hien *et al.* 1998). In a study of 42 rice-based farms in Vietnam into which *M. rosenbergii* had been introduced, Nguyen *et al.* (1993) showed that a 72% increase in net farm income was produced with very little increase in labour. While rice contributed 42% to net farm income and prawns 32%, prawn production comprised 43% of the cash income, compared to only 20% from rice. This was because prawns were sold as a high-value cash crop, while rice was destined for domestic markets. Recently, it has been reported (Chapter 17) that the introduction of freshwater prawns in Vietnam results in an increase in income of US$ 600 to 1000/ha.

In summary, a significant amount of applied research has been done on potential commercial techniques of culturing freshwater prawns in conjunction with other species, especially fish. Lee & Wickins (1992) stated that commercial polyculture involving prawns has generally not been very successful. For example, Taiwanese farmers were successful in developing the commercial polyculture of freshwater prawns with catfish, carps, and tilapia, but returned to prawn monoculture due to harvesting and predation problems with prawn–fish polyculture (Hsieh *et al.* 1989). In contrast, recent information gathered in the course of preparing this book indicates that polyculture of freshwater prawns occurs in China, sometimes as a primary crop and sometimes as a secondary crop to fish culture. Furthermore, prawn polyculture and integrated culture are commonly practised in Bangladesh, Vietnam and other countries (see Chapters 12 and 17).

20.5 Economic modelling of commercial prawn farming

The economic analysis of freshwater prawn farming reviewed in previous sections has generally been based upon simple costs and returns budget models of hypothetical (synthetic) farms or averages from economic surveys of prawn producers. In most cases, these budget models are based upon accepted production norms (e.g. average grow-out survival rates and harvest sizes, etc.), and critical inputs such as feed, seed, and labour are assumed to be applied in fixed proportions based upon industry norms (Leung *et al.* 1984). These budget models, whether based upon hypothetical farms or industry surveys, can be useful in the overall economic feasibility of prawn farming or in documenting industry trends, but they have limited utility for providing individual farm managers with quantitative tools to improve profits and reduce risk. In contrast, bio-economic models have the potential of providing the farm manager with operational and design insight. Bio-economic models can also be employed to aid policy-makers in delineating optimal management strategies and system designs as well as assisting in the identification of critical factors for future research. Moreover, in some situations, it may be more cost-effective to conduct research via a model of a complex aquacultural system than to implement costly field experiments.

Publications that provide a good review of aquaculture modelling include Allen *et al*. (1984) and Cuenco (1989). Leung (1994) provided a classification and review of bio-economic modelling research from 1984 to 1993 related to aquaculture enterprises including freshwater prawn farming. This author defined bio-economic models as a mathematical description of an aquaculture enterprise, which relates physical, biological, and economic variables into a systematic and holistic analysis. The advancement and adoption of relatively inexpensive computer technology, especially microcomputers, has obviously facilitated the application of bio-economic modelling of aquaculture enterprises as a tool for economic research (Shang 1990) during the last two decades of the 20th century.

20.5.1 Bio-economic models

Using weekly experimental data from Polovina & Brown (1978), Azizan (1983) developed a bio-economic simulation model for determining the optimal (i.e. net profit maximisation) batch harvest period for prawns by assuming that variables other than time and stocking density did not affect growth. Leung & Shang (1989) used Hawaiian commercial prawn farming data and dynamic programming techniques to estimate optimal stocking and harvesting strategies. For Bangladesh, Bala & Satter (1989) determined optimal management and operation techniques using both experimental and commercial farming data plus linear programming and system dynamics.

Leung *et al.* (1993) compared the bio-economic modelling of experimental, intensive penaeid shrimp farming techniques (Wyban *et al.* 1988) with a model of freshwater prawn farming in Hawaii. Their prawn bio-economic model was based upon Leung & Shang (1989), and the marine shrimp model was derived from Hochman *et al.* (1990). Both models used stochastic dynamic programming and employed various decision rules with the overall objective of improving management efficiencies under uncertainty. Although the models had differences due to data requirements, risk sources, and final solution algorithms, the major difference was the growth characteristics of cultured marine shrimp and prawns. Since cultured marine shrimp generally grow uniformly and are usually batch harvested, shrimp populations in the ponds were modelled as a growing inventory. In contrast, cultured prawn growth due to heterogeneous individual growth is non-uniform and harvesting is often selective (continuous) (Leung *et al.* 1993). Their prawn model treated the prediction of size distribution and biomass of the pond population as an uncertainty once the pond was stocked, while their marine shrimp model focused on the uncertainty associated with random growth rates and prices.

20.5.2 Risk modelling

Risk can be simply defined as the possibility of some unfavourable occurrence. Aquaculture enterprises obviously face significant risks unless they adopt risk management strategies (Secretan 1988). These strategies include careful initial design of the facility, for example the size of the individual ponds. Using historical commercial prawn production data, Samples & Leung (1985) generated a stochastic model to determine if yield variability was a source of financial risk for prawn producers in Hawaii. Based upon a wholesale price of US$ 11.00/kg, their model predicted that there was a 50% probability that a typical 8 ha Hawaiian prawn farm with 0.8 ha ponds could incur a financial loss in any given year. In addition, this probability would decline to 30% if ponds smaller than 0.4 ha were employed. Griffin *et al.* (1993) found that initial construction cost per ha for a 40 ha marine shrimp farm in the USA declined substantially while the farm's projected IRR increased if the number of ponds was decreased and the size of each pond was increased. Although it may be desirable to reduce initial investment costs by building several 'large' ponds *versus* many 'small' ponds, the model of Samples & Leung (1985) also suggests that there could be an optimal pond size for managing commercial prawn grow-out culture relative to reducing yield variability risks. Perhaps the observation of New & Singholka (1985) that most prawn farming ponds are in the 0.2 to 0.6 ha range may also reflect industry experience with reducing yield variability, not just harvesting considerations, and land availability.

20.6 References

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21
Culture of Other Prawn Species

Methil Narayanan Kutty, François Herman and Hervé Le Menn

Approximately 200 species of freshwater prawns of the genus *Macrobrachium* are circumtropical in distribution and native to all continents other than Europe (Holthuis 1980; see Chapter 2) but, until the late 1990s, only one species (*M. rosenbergii*), was known to be truly commercially established in aquaculture. Recently (1999) a smaller species (section 21.1) has been reported as being cultured in China, which is certainly the second most important farmed freshwater prawn. This species, *M. nipponense*, has been cultured so successfully that it may overtake giant prawn farming in China shortly, due to its taste and its capacity to survive in colder environments (Miao Weimin, pers. comm. 1999).

Ling & Costello (1979) and Holthuis (1980) listed several species of *Macrobrachium* that have great potential for aquaculture and that were under research for farming in many countries during the 1970s. However, most research programmes on *Macrobrachium* spp. other than *M. rosenbergii* ceased in the 1980s and 1990s and, nowadays, knowledge about the majority of these species remains at the same stage as it was in the 1980s.

Until the late 1990s, the size of the candidate species had been one of the major desirable characteristics in species selection in freshwater prawn farming. However, as is obvious from the example of *M. nipponense*, other factors also come into play. For those species that are yet to fully qualify as farmed, a combination of favourable aquacultural characteristics and consumer acceptance factors will govern which will be chosen for farming. A list of over 20 species, which are under various stages of recruitment to aquaculture in the above context, is provided in Table 21.1. In addition to *M. nipponense*, which is now under substantial commercial culture, the most serious contenders for reaching commercial status are *M. malcolmsonii* in the Indian subcontinent, *M. carcinus* in Central America and *M. amazonicum* in South America. Apart from these four species, most of the research that has been conducted to date has concentrated on the biology of the various species, information on which is a prerequisite to the development of larval and grow-out culture systems. Aspects of bioenergetics and ecophysiological adaptations and the biochemistry of various species have been studied and at least one study deals with transgenics. Recent catastrophes in aquaculture, especially in marine shrimp culture, owing to auto-degradation of the culture system and diseases (Lin 1989; Kutty 1997) highlight the need to direct more attention to understanding basic physiological and behavioural characteristics of the cultivable species. These, and their environmental interactions, will permit an optimisation of yield while minimising environmental degradation. All the species listed in Table 21.1, and in the text of this chapter, have a variety of local names. However, for clarity, the names used here are their 'official' English Food and Agriculture Organization (FAO) names (Holthuis 1980).

21.1 Oriental river prawn (*Macrobrachium nipponense*)

Holthuis (1980) noted that *M. nipponense* (Fig. 21.1) was common in the fisheries of China, and was exported from Hong Kong all over the world. According to this author, there was also a fishery for this species in Vietnam and in Japan, where

Table 21.1 List of *Macrobrachium* species (other than *M. rosenbergii*) which are farmed or are thought to have aquaculture potential, according to the literature.

Species	Indigenous location[a]	Adult habitat[b]	Culture status[c]	Reference[d]
M. acanthurus	Atlantic Americas: from North Carolina to Caribbean islands and South Brazil	FW/BW	E	(1) (2) (37)
M. amazonicum	Atlantic South America: from Venezuela to Paraguay	2 strains: FW/BW and FW	E	(1) (34) (35) (36)
M. americanum	Pacific Americas: from Baja California (Mexico) to North Peru, including the Cocos and Galápagos islands	FW	E	(1) (2) (3)
M. birmanicum	Indo-West Pacific: East India, Bangladesh, lower Ganges basin and lower Irrawaddy basin, Burma	FW/BW	E	(1) (4)
M. carcinus	Atlantic Americas: from Florida to the Caribbean islands and Southeast Brazil	FW/BW	E	(1) (38) (39)
M. choprai	Indo-West Pacific: Ganges and Brahmaputra river systems	FW	E	(1) (5) (6)
M. dayanum	Indo-West Pacific: Pakistan, India, Bangladesh	FW	E	(1)
M. dux	Eastern Atlantic: West Africa from Rio Muni to Zaire	FW	E	(1) (27)
M. equidens	Indo-West Pacific: Madagascar to South China, New Caledonia	FW/BW	E	(1) (2) (6) (7) (8)
M. felicinum	West Africa: Nigeria	FW	E	(27)
M. idae	Indo-West Pacific: Madagascar to the Philippines, Indonesia	FW/BW	E	(1) (2) (9) (10) (11) (33)
M. idella	Indo-West Pacific: East Africa, Madagascar, India	FW/BW	E	(1) (12) (13)
M. jelskii	Atlantic America: from Costa Rica and Trinidad to Venezuela and Brazil	FW/BW	E	(1) (14)
M. kistensis	Indo-West Pacific: India	FW	E	(2)
M. lanchesteri	Indo-West Pacific: Thailand, Malaysia, India	FW/BW	E	(1) (2) (3) (15) (16)
M. lamarrei	Indo-West Pacific: India, Bangladesh	FW/BW	E	(1) (5) (6) (17) (18) (19)
M. macrobrachion	Eastern Atlantic: Senegal to North Angola	FW/BW	E	(1) (28) (29) (30)
M. malcolmsonii	Indo-West Pacific: India, Pakistan, Bangladesh	FW/BW	A	(1) (24) (31) (32) (40) (41)
M. mirabile	Indo-West Pacific: East India, Bangladesh, Burma, Thailand, Malaysia, Indonesia	FW/BW	E	(1) (3) (5) (6) (24)

Table 21.1 *Continued.*

Species	Indigenous location[a]	Adult habitat[b]	Culture status[c]	Reference[d]
M. nipponense	Indo-West Pacific: North China to Annam, Taiwan, Japan	2 strains: FW/BW and FW	C	(1) (42) (43) (44) (45)
M. nobilii	Indo-West Pacific: India	FW	E	(6) (20) (21) (22) (23)
M. olfersii	Western Atlantic: Florida and Texas, Mexico, to South Brazil. Absent from the West Indies	FW	E	(1) (25) (26)
M. rude	Indo-West Pacific: East Africa, Madagascar, India, Bangladesh	FW/BW	E	(1) (6)
M. villosimanus	Indo-West Pacific: Northeast India, Bangladesh	FW	E	(1) (2) (5) (6)
M. vollenhovenii	Eastern Atlantic: Cape Verde Islands and Senegal to South Angola	FW/BW/SW	E	(1) (2) (27) (28) (30) (31)

[a] According to Holthuis (1980), except for *M. felicinum*, *M. kistensis, M. nobilii.*

[b] FW, BW and SW denote freshwater, brackishwater and seawater, respectively.

[c] Highest status of culture achieved to date. C = commercial culture established; A = artisanal culture existing; E = experimental or research and development (current or past).

[d] (1) Holthuis (1980); (2) New (1995); (3) Brown (1991); (4) NACA (1998); (5) Jhingran (1991); (6) Jayachandran & Joseph (1992); (7) Natarajan *et al.* (1992); (8) R. Tamatamah (pers. comm. 1999); (9) Kingston *et al.* (1992a); (10) Kingston *et al.* (1992b); (11) Katre & Pandian (1972); (12) Ignatius & Thampy (1990); (13) Kurup *et al.* (1992); (14) Mendes *et al.* (1998); (15) Johnson (1969); (16) Bensheng & Khoo (1997); (17) Marian *et al.* (1986); (18) Rao (1992); (19) Singh & Qureshi (1997); (20) Balasundaram & Pandian (1982a); (21) Balasundaram *et al.* (1982b); (22) Kumari & Pandian (1987); (23) Kumari & Pandian (1991); (24) Ibrahim (1962); (25) White (1977); (26) Anderson & Fillingame (1980); (27) Mwangi (1984); (28) Marioghae (1987); (29) Kavu (1985); (30) Enin (1995); (31) Bello-Olusoji *et al.* 1998; (32) Ninawe (1998); (33) Natarajan *et al.* (1987); (34) Odinetz-Collart (1991); (35) McNamara *et al.* (1983); (36) Moraes-Riodades (1999); (37) Choudhury (1970); (38) F. Herman (pers. comm. 1999) and P. Boucher (pers. comm. 1999); (39) Choudhury (1971a); (40) Rajyalakshmi (1980); (41) Yaqoob (1994); (42) Wong & McAndrew (1994); (43) Miao Weimin (pers. comm. 1999); (44) Wang & Qianhong (1999); (45) Shi *et al.* (1994).

some experiments towards its culture had taken place. Recently, *M. nipponense* has been found in fish ponds in northern Iran, close to the Caspian Sea (L. Holthuis, pers. comm. to M. New 1999); this was probably due to an accidental introduction that occurred during finfish stocking. In China, the species is sometimes referred to as *M. japonica* (Miao Weimin, pers. comm. 1999) but this is misleading; *M. nipponense* is a totally different species to *M. japonicum*, which has been reported only in Taiwan, Japan, and the Bonin Islands and has no known economic importance in capture fisheries or aquaculture (L. Holthuis, pers. comm. 1999). It has also been referred to as *M. nipponensis* (Wang & Qianhong 1999). In this chapter, the oriental river prawn will be referred to by its correct name, *M. nipponense.*

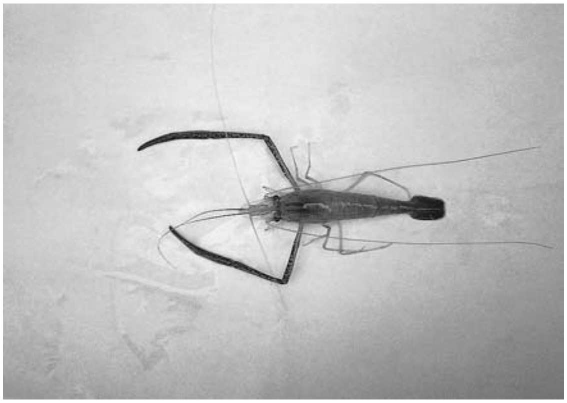

Fig. 21.1 *Macrobrachium nipponense*. (Source: Maio Weimin, China.)

Macrobrachium nipponense, whose maximum size is 86 mm (male) and 75 mm (female) according to Holthuis (1980), is one of the few members of the genus *Macrobrachium* that has a temperate distribution (Wong & McAndrew 1994) and its freshwater and brackishwater habitat was noted by Holthuis (1980). Wong & McAndrew (1990) showed that a population in Hong Kong with a larval survival optimal salinity of 10 p.p.t. had a high realised heritability for larval freshwater tolerance. By selection over three generations these authors produced a strain of *M. nipponense* that could complete its life cycle in freshwater, thus showing that adaptation to a wholly freshwater existence could occur fairly rapidly in populations isolated by flooding or impoundment. The strain that is cultured in China is reported to complete its life cycle in freshwater (Miao Weimin, pers. comm. 1999), indicating that its origins were from habitat(s) isolated from brackishwater. Wang & Qianhong (1999) also report that this species can reproduce in natural (inland) waters.

It has been estimated that the annual Chinese farmed production of *M. nipponense* was at least 15 000 t in 1998 (Wang & Qianhong 1999). While this is not as substantial as the production of *M. rosenbergii* in China (Chapter 17), this means that the volume of production of the oriental freshwater prawn there is greater than the national production of the giant freshwater long-legged prawn in any other individual country. The details given in the remainder of section 21.1 of this chapter are based (except where otherwise noted) on a report (Miao Weimin, pers. comm. 1999) on current experience in China, which is the only country currently commercially culturing the species. Since the prawn can survive winter under natural conditions and the larvae have no special requirement of salinity, rearing and artificial breeding of the prawn is simple compared with *M. rosenbergii*. These features make *M. nipponense* more popular than *M. rosenbergii* for culture in some parts of China, particularly in Jiangsu province (north of Shanghai) where nearly 40 000 ha were under production by 1998 (Wang & Qianhong 1999). The oriental prawn is much smaller at harvest than *M. rosenbergii*; however, it is curious to note that these authors report 1998 prices, which vary seasonally, of 35 to 120 yuan/kg (US$ 4.34–14.87/kg) for *M. nipponense* but only 15 to 35 yuan/kg (US$ 1.86–4.34/kg) for *M. rosenbergii*. The price for *M. rosenbergii* was reported to have decreased, due to declines in size at harvest (genetic degeneration). Current prices for *M. rosenbergii* are provided in Chapter 17.

21.1.1 Seed production

Prawn seeds are collected from natural waters or are bred in captivity. Mature females are observed at <50 mm and the breeding season in China is May to July. Egg incubation is 20 days at 25°C and fecundity is 500 to 5000 per female. For artificial breeding, brooders (50 mm) are collected from natural waters or from the culture ponds and stocked in cement tanks (300 m^2 area and 1 m depth) at a stocking density of 100 to 200/m^3 or in earthen ponds (0.07–0.14 ha) at 30 000 to 60 000/ha. The prawns are fed at 1 to 3% biomass when the temperature is over 10°C. The brooders are restocked (same stocking density; male to female ratio 1:2–3) in spring in earthen ponds (0.1–0.3 ha and 1.5 m deep), with one-quarter of the pond area planted with submerged weeds to provide shelter for the prawns. The prawns are fed at 5 to 6% biomass with various feeds (soybean cake, wheat bran, fish meat, clam meat, pelleted feed). The prawns start to spawn naturally in the ponds in May and the eggs hatch in 20 days at 25°C. Larvae are reared in the pond itself (fertiliser and feed are applied for the larvae) or are reared separately. Wang & Qianhong (1999) noted the importance of the relationship between plankton density and water quality during this stage of rearing; fertilisation increases the total quantity of zooplankton, which can be enhanced by culturing rotifers. It is interesting to note that *M. rosenbergii* larvae have also been reared in earthen ponds, as opposed to the traditional hatchery systems, in Thailand as well as in China (Chapter 5).

Small cages (1 × 0.5 × 0.5 m) kept inside ponds are also used for hatching eggs and rearing larvae; besides fertilisation, soybean milk is fed to the larvae. In 25 days the larvae reach the post-larval stage (10 mm). Details of the larval stages of *M. nipponense* are included in Table 21.2.

Postlarvae (PL) are usually reared to juveniles before stocking in grow-out ponds. Both cement tanks and earthen ponds are used. Postlarvae

Table 21.2 Comparative larval development characteristics of selected *Macrobrachium* spp.

Species	No. of zoeal stages	Duration (days) to PL1	Temperature (°C)	Salinity (p.p.t.)	Feed given	Reference
M. acanthurus	10	32–42	?	21	Chopped fish, crustacean muscles and *Artemia*	Choudhury (1970)
M. amazonicum	9[a]	20	28	12	*Artemia* nauplii and egg custard	Moraes-Riodades *et al.* (1999)
M. carcinus	12	55–66	24–28	14–16	Chopped fish, crustacean flesh and *Artemia*	Choudhury (1971a)
	12	45	28	16	*Artemia* nauplii and particles of a squid egg, vitamins and cod liver oil mixture	F. Herman, pers. comm. (1994); Herman *et al.* (1999)
M. malcolmsonii	11	52	22–30	14–19	*Tubifex* pieces	Rao (1991)
	8[b]	43–63	28–31.5	11[b]	*Artemia* nauplii, fish eggs, boiled fish, copepods	Yaqoob (1994)
		29–45	28–30 (29)[d]	18–21[c] (19.5)[d]	*Artemia* nauplii	Kanaujia *et al.* (1996)
		41–43	28–30 (29)[d]	18–22[e] (20)[d]	*Artemia* nauplii	Kanaujia *et al.* (1996)
M. nipponense	9	18–20	23–26.5	8.3–9.3	*Artemia* nauplii	Kwon & Uno (1969)
M. rosenbergii	11	33–36	27.5–28.5	12–12.3	*Artemia* nauplii	Uno & Kwon (1969)

[a] Guest (1979).
[b] Tests at 11 p.p.t. salinity or below only.
[c] Tests in natural seawater, survival 22–23%.
[d] Average value.
[e] Tests in synthetic seawater, survival 12–23%.

are stocked at 250 to 300/m^2 in cement nursery tanks (100 m^2 and 1 m depth), provided with a channel (1.0–1.5 m deep, 0.5–0.7 m wide) at the bottom to facilitate harvesting of juveniles at the end of the rearing period. The feed is the same as for brooders. Juveniles are harvested after 20 days of rearing.

Wang & Qianhong (1999) noted that, while comprehensive studies have not yet been conducted, *M. nipponense* juveniles produced from pond-reared parents are reported to have a smaller average size than those reared from berried females collected from lakes. Clearly, this indicates that much research into broodstock development remains to be done for this species, as well as for *M. rosenbergii* (see Chapter 4).

21.1.2 Grow-out culture

Three types of grow-out system exist, namely pond culture, cage culture and paddy-cum-prawn culture. Ponds are typically 0.1 to 0.2 ha in area and 1.0 to 1.5 m deep. Juvenile prawns (2000–5000/kg) are stocked at 60 to 70/m^2; supplementary stocking takes place after selective harvesting. The prawns are fed farm-made mixtures of soybean cake, wheat bran, fish meal, clam meat, and pelleted feeds. Wang & Qianhong (1999) reported that annual yields range from 390 to 1875 kg/ha.

Macrobrachium nipponense is also reared in polyculture with fish. In this case, prawns may be stocked at 45 to 60/m^2, where prawns are dominant, or 15 to 30/m^2, where fish production is the dominant target. Annual yields per hectare are typically 1500 kg of prawns and 2250 to 3000 kg of fish or 300 to 450 kg of prawns and 4500 kg of fish, respectively.

In cage culture, floating cages (10 × 3 × 1.3 m) are commonly used and two crops of prawns are harvested. The first stocking (of 0.5 to 1 g juveniles, stocked at 80–100/m^2) occurs in March and the second (0.2–0.5 g, stocked at 120–150/m^2) in July. Daily feeding is made at 5 to 8% biomass. The yield is estimated as 0.5 kg/m^2.

Paddy-cum-prawn culture is similar to that of *M. rosenbergii* (Chapter 12). A week after transplantation of rice seedlings, 150 000 to 225 000 juveniles (0.2–0.5 g) are stocked per hectare. Feeding is the same as for pond culture. Paddy pesticides need to be avoided and adequate water depth maintained. Yields of 150 kg/ha can be obtained.

21.2 Monsoon river prawn (*Macrobrachium malcolmsonii*)

The monsoon river prawn *M. malcolmsonii* (Fig. 21.2) has a maximum size of 230 to 243 mm (male), and 200 mm (female) (Holthuis 1980; Jayachandran & Joseph 1992; Venketaswamy 1993). There is a well-established commercial fishery for this species in the Ganges and Godavari rivers in India (Ibrahim 1962; Jhingran 1991; Tripathi 1992), in the Indus river in Pakistan (Yaqoob 1994), and also in the Ganges–Brahmaputra delta in Bangladesh (Akand & Hasan 1992). In India it is widely cultured at an artisanal level (Rajyalakshmi 1974; Jhingran 1991) and is beginning to enter commercial culture in India (Kanaujia & Mohanty 1996; N. Sukumaran & J. Christopher, pers. comm. 1999) This species has also been reared at an experimental level in Pakistan (Yaqoob 1987, 1994). In all these cases, farming is based upon the use of wild-caught seeds, which are usually abundant in the major rivers of the sub-continent. Lately, some attempts to develop large-scale production of hatchery seeds are in progress in India (Kanaujia & Mohanty 1992; Kanaujia *et al*. 1997).

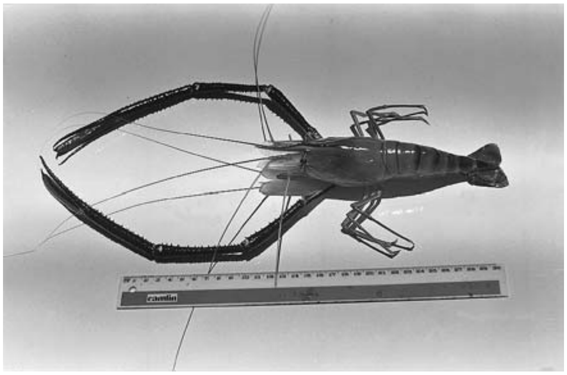

Fig. 21.2 Adult male *Macrobrachium malcolmsonii*. (Source: Stephen Sampathkumar, India.)

According to the Marine Products Export Development Authority of India (MPEDA) the production of ‘white scampi’, as the exporters call *M. malcolmsonii*, constitutes about 10% of total farmed production of freshwater prawns in India.

A commercial fishery for *M. malcolmsonii* yielding 100 t/yr exists in Pakistan, but grow-out trials are still experimental (Yaqoob 1994), in spite of the fact that successful laboratory larval rearing has occurred (Table 21.2). Work on the larval rearing of *M. malcolmsonii* in Pakistan was published by Yaqoob (1987). However, technical problems occurred in this trial which resulted in the work being abandoned at the final larval stage; metamorphosis was not achieved (New 1996). There are no reports of the culture of this prawn in Bangladesh, even though it contributes to fisheries production (Akand & Hasan 1992).

21.2.1 Seed production

The adult monsoon river prawn matures and breeds in rivers and lakes, the larvae move down to estuarine waters along with the flood waters, and the juveniles return to freshwaters, climbing dams and anicuts (irrigation dams) in the east flowing rivers of India (Ibrahim 1962; Rajyalakshmi 1980; Rao 1986; Venketaswamy 1993; John *et al*. 1998). Several workers (Yaqoob 1987; Rao 1991; Kanaujia & Mohanty 1992; Kanaujia *et al*. 1996) have studied its larval development; selected results are included in Table 21.2. The size of females at first maturity in the Godavari river was reported to be 42 mm by Ibrahim (1962), while Rajyalakshmi (1980) reported them to be 68 mm in the Godavari river and 83 mm in the Hooghly estuary. Thus, mature prawns are observed first in riverine habitats. The breeding season in India is from April to December, with a peak in August to November, depending on the monsoon. Egg incubation is 13 days (Ibrahim 1962; Rajyalakshmi 1980; Rao 1992). Fecundity has been reported to range from about 3500 to 94 000 for females of 54 to 165 mm (Ibrahim 1962; Rajyalakshmi 1980; Venketaswamy 1993).

Studies on the effect of nutrition on broodstock performance by Samuel *et al.* (1999) have revealed that male reproductive performance, as judged by relative spermatophore weight and live sperm count, is seriously affected by feed quality. The spermatophore weight decreased to 71% when clam meat alone was fed daily; when it was fed on alternate days it declined to 43%. Similarly, the live sperm count fell to zero in 7 to 8 weeks and the number of abnormal sperm increased significantly (60–80%). On the other hand, when a mixture of clam meat, squid and pelleted feed was used, the spermatophore weight and live sperm count remained unaltered during the 8 weeks of observation and there was no increase in abnormal sperm.

As indicated earlier, almost all grow-out production is based on stocking wild-caught juveniles, the prime centres of collection being situated on the Godavari, Mahanadi and Cauvery rivers. In these locations the Government organised juvenile capture and distribution for pond culture and for stocking in open waters to enhance natural fisheries (see Chapter 22). Most of this stocking is for the polyculture of freshwater prawns with Indian and Chinese carps, but some monoculture is also in progress. However, the available supply of wild-caught juveniles is inadequate and grow-out production could be increased when hatchery-produced seeds become available. Juveniles (50 mm; 1.08 g) stocked at a density of 3/m^2 in a 0.1 ha pond grew to 111 mm (19.2 g) in 117 days, while 36 mm (0.44 g) juveniles grew to 119 mm (25.3 g) in 120 days (Rao 1989). Tagged (Peterson disc tag) *M. malcolmsonii* grew at a rate of 11.1 mm and 7.2 g/month.

Research on the controlled breeding of *M. malcolmsonii* continues. Kanaujia *et al.* (1999) reported that when adult prawns were stocked at 15/m^2 in a recirculation system at 27 to 30°C with a 1 : 5 male : female ratio, breeding occurred year-round. Significantly more berried females were observed when the intensity of illumination was higher; the peak occurred between June and September. However, the highest number of larvae per gravid female occurred in January to March and the lowest number between July and September.

Interbreeding of *M. malcolmsonii* and *M. rosenbergii* has been attempted (Soundarapandian *et al.* 1995). Successful spawning took place but none of the eggs hatched. Unilaterally eye-ablated female *M. malcolmsonii* (25–34 g) had a fecundity of 48 476 to 59 786 and a larval survival rate of 50 to 53%.

21.2.2 Grow-out culture

Macrobrachium malcolmsonii is an omnivore/detritivore, its gut contents containing mud and debris, dipteran larvae, and cladocerans (Ibrahim 1962). It also feeds effectively on live prey such as carp and tilapia fry, and tadpoles (Sukumaran & Kutty 1979).

21.2.2.1 Monoculture

Early grow-out production figures (1974–1983) from monoculture ponds ranged between 327 and 774 kg/ha/yr (Kanaujia & Mohanty 1992). Several other trials have been reported (Reddy *et al.* 1988; Rao *et al.* 1992; Thangadurai 1992; Kanaujia *et al.* 1997). Rao *et al.* (1992) stocked 30 000 wild juveniles (25–32 mm) per hectare in four 146 m^2 earthen ponds, fed a mixture of snail (*Pila globosa*) meat (10%), mussel meat (25%), groundnut oil cake (20%), maize (30%), other cereals (13%) and mineral mix (2%), and obtained a survival of 50 to 75% and a yield of 524 to 744 kg/ha/yr (water temperature 23–37°C). In a control pond (no feeding) the production was 213 kg/ha/yr. These authors found that 2% of the harvested prawns were infected by a bopyrid parasite. Interestingly Ibrahim (1962) observed that, at times, more than 50% of wild prawns were infected with the same parasite.

The following information about current monoculture practice has been extracted from Kanuajia & Mohanty (1996) and Kanuajia *et al.* (1997). Ponds are typically 0.1 to 1.0 ha in area and 1.0 to 1.5 m deep. In the case of undrainable ponds (which are the majority) mahua oil cake (*Madhuca* spp.) at 200 to 250 p.p.m. or urea/bleaching powder at 5 p.p.m. is used to kill unwanted fish during their preparation. One week later the ponds are fertilised with 5 to

10 t/ha of cow manure and lime is applied monthly at 100 kg/ha. After a further 2 weeks, 20 to 60 mm wild-caught juveniles are stocked at 3 to 10/m^2. A 30 to 40% protein farm-made feed, typically made from oil cakes, tapioca, small shrimp (*Acetes* sp.), apple snails (*Pila globosa*), prawn waste, trash fish, poultry feed, etc., is fed at 3% of biomass. Batch or multiple selective harvesting is practised. At a stocking density of 3/m^2, the yield varies from 440 to 553 kg/ha after 6 months, while 505 to 565 kg/ha/6 months is achieved when prawns are stocked at 5/m^2. Survival ranges from 50 to 52% at the lower stocking density to 26 to 32% at the higher. Much higher stocking densities (up to 100/m^2) have been also tried but survival and yield were poorer.

Das *et al*. (1995) found that when juveniles were fed with formulated diets (four different protein sources, namely fish meal, prawn meal, mussel meal and silkworm, in isonitrogenous diets with 35% protein and a caloric content of 3.8 to 4.1 kcal/kg) the best results were obtained with a 40% inclusion rate of prawn meal.

There are several problems in *M. malcolmsonii* grow-out culture in India (Raman 1992). Many of these relate to conflicts between the traditional use of already existing 'tanks' (small undrainable irrigation reservoirs) and ponds, and the introduction of prawn culture. Improvement in management could alleviate most of the difficulties encountered.

21.2.2.2 Polyculture

Macrobrachium malcolmsonii has been reared in polyculture with a number of Indian and other carps, including catla (*Catla catla*), rohu (*Labeo rohita*), silver carp (*Hypophthalmichthys molitrix*), grass carp (*Ctenopharyngodon idella*) and common carp (*Cyprinus carpio*).

In trials using 146 m^2 earthen ponds to measure the effect of competition when *M. malcolmsonii* was reared in polyculture, Reddy *et al*. (1988) stocked 60 000 prawn juveniles/ha in different combinations: (1) prawn (P) + catla + rohu; (2) P + catla-rohu hybrid + rohu; (3) P + rohu; (4) P + grass carp; and (5) P + common carp. The carp densities varied from 1860 to 4000/ha. The prawns were fed daily with 100 g of minced apple snail *(Pila globosa)* meat per pond. Grass carp were fed with *Hydrilla* spp. at 50% body weight. Following multiple harvests after 120 to 320 days of culture, prawn production varied from 62 to 882 kg/ha (average 443 kg/ha), and survival ranged from 7 to 69%. The lowest prawn survival rates of 7% and 14%, and production rates of 86 kg/ha and 62 kg/ha, were obtained in trials with prawns stocked with grass carp and common carp respectively [combinations (4) and (5)]. The highest survival (69%) and production (882 kg/ha) rates were achieved by the 3-species (prawn, catla and rohu) combination (1). In combination (2) (P + catla-rohu hybrid + rohu), prawn production was 503 kg/ha and survival 51%. These results indicate that polyculturing prawns with either common carp or grass carp alone is not compatible, due to serious competition for the same food niche or, possibly, behavioural interactions. However, polyculture with mixtures of the Indian major carps, catla and rohu, which occupy the surface and water column niches, does not pose any problem of compatibility. However, there were no trials with mrigal, which occupies the bottom niche and might be antagonistic to prawns in polyculture.

The polyculture of *M. malcolmsonii* with carps in farmers' ponds in Tamil Nadu (India) indicate that the system appears to be economically successful. The stocking of larger ponds and 'tanks' (see section 21.2.2.1) is spreading in areas where wild-caught juveniles are available. Kanuajia & Mohanty (1996), reported that prawns were stocked at 15 000 to 20 000/ha with 3000 to 7000 catla, rohu, silver and grass carps. An annual average of 327 kg of prawns were harvested with 2084 kg of fish per hectare. An unpublished survey of results from six farmers' ponds (size range 2.0–5.6 ha), which was prepared during the development of this chapter by N. Sukumaran & J. Christopher (pers. comm. 1999), showed that prawns were stocked at 10 000 to 12 500/ha in polyculture with carps. The yield was 142 to 165 kg of prawns (215–280 g; survival 55–70%) in 7 to 8 months. The prawns contributed 6.5 to 7.2% of total pond production.

21.3 Painted river prawn (*Macrobrachium carcinus*)

The yield of the painted river prawn (*M. carcinus*) (Fig. 21.3) has been exploited commercially through artisanal fishing in several countries (Ling

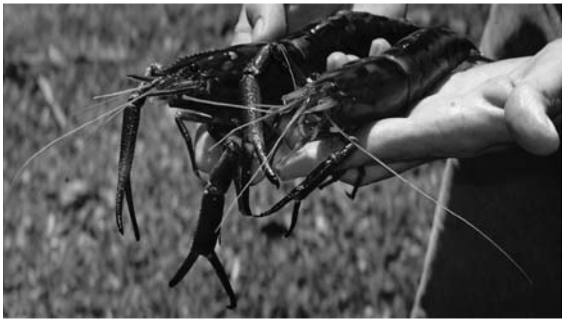

Fig. 21.3 *Macrobrachium carcinus*. (Source: Hervé Le Menn, Guadeloupe.)

& Costello 1979; Holthuis 1980; Rabanal 1982; Chauvin 1992). However, its catch has been declining recently, due to pollution, the destruction of natural ecosystems, and over-fishing (Valenti 1993; Herman *et al.* 1999), caused by the high local demand as a gourmet food. Successful trials in farming this species have been made recently in Guadeloupe (Herman *et al.* 1999), but the technology is yet to spread at the commercial level.

Macrobrachium carcinus is certainly one of the largest freshwater prawns (Dugan & Frakes 1973; Fievet 1998). Males have been reported to reach 230 to 300 mm by Holthuis (1952, 1980) and Dugan & Frakes (1973) and females to reach 170 mm (Holthuis 1952, 1980). A 6-year-old female of 210 mm (190 g) was reported by Valenti *et al.* (1994). A male of 850 g has been observed (F. Herman, pers. comm. 1999). This species is said to prefer shady areas with plants and rocky shelters. An omnivore/detritivore, it is highly aggressive and territorial, particularly when the prawns exceed 25 mm (Lewis *et al.* 1966). The prawn can skirt around waterfalls by crawling on the ground (c.f. *M. malcolmsonii*, section 21.2).

This species breeds during the rainy season, e.g. May to October in Barbados (Lewis *et al.* 1966), June to November in Guadeloupe (Hostache 1992) and February to March in Brazil (Valenti *et al.* 1986). The size at first maturity has been reported as 55 g (Valenti *et al.* 1994). Egg incubation takes 19 days (Graziani *et al.* 1993). Fecundity (Lobão *et al.* 1985), reproduction and growth (Valenti *et al.* 1986, 1994; Lobão *et al.* 1986b) in natural populations of this species have been studied in Brazil. Lobão *et al.* (1985) observed that 40 to 60 g females produced about 23 000 eggs. Valenti *et al.* (1994) observed that *M. carcinus* (20 mm) grew to 110 mm in 14 months in the natural environment. In grow-out trials, PL can reach an average weight of 29 g in 7 months and 65 g in 14 months, but exhibit a strong heterogeneity (F. Herman & P. Boucher, pers. comm. 1994). Length/weight relationships for *M. carcinus* and *M. rosenbergii* are compared in Fig. 21.4.

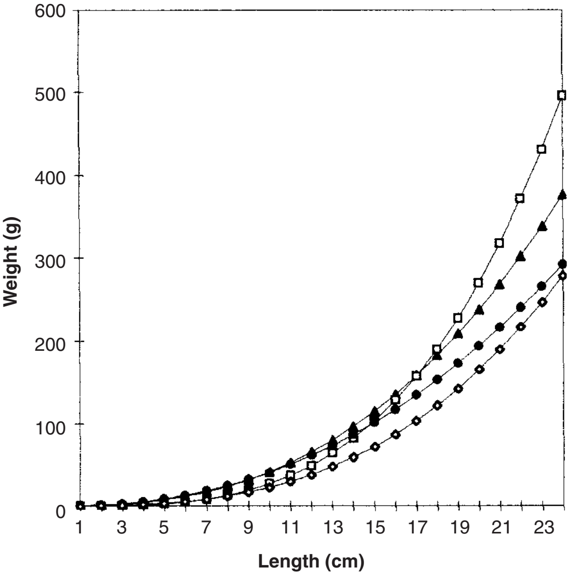

Fig. 21.4 Length/weight relationships of *Macrobrachium carcinus* (M.c.) and *M. rosenbergii* (M.r.). (Source: Valenti *et al.*, 1994 and F. Herman, unpublished data 1994.)

Key: ▲ = M.c. male; □ = M.r. male; ● = M.c. female; ◇ = M.r. female.

21.3.1 Seed production

Details of the larval development of *M. carcinus* are included in Table 21.2. Larval rearing was mainly studied in the USA, Brazil, Venezuela and the West Indies, including Guadeloupe. The duration of the larval cycle is longer for *M. carcinus* (45–65 days) than for *M. rosenbergii* (30–35 days) and the survival rates achieved to date have been much poorer. Several studies have examined its optimal salinity (Lewis & Ward 1965; Choudhury 1971b; Moreira *et al.* 1988; Herman *et al.* 1999). Graziani *et al.* (1993) observed that the optimal salinity of developing larvae increases at a rate of 1 to 2 p.p.t./day, reaching a plateau at 15 p.p.t. on the ninth day, from which it does not increase further. On the contrary, Herman *et al.* (1999) observed that the best results were obtained when larvae were reared at a constant salinity of 16 p.p.t., but the larvae can tolerate higher salinities up to 21 p.p.t. Valenti (1985) recommended 20 to 24 p.p.t. These differing results suggest that there are still unresolved problems in the larval salinity requirements of this species.

The first larval stages of *M. carcinus* are fed with *Artemia* nauplii (Table 21.2) but, after 10 to 12 days (larval stage IV), the larvae are attracted by larger prey. Unlike *M. rosenbergii*, the larvae of *M. carcinus* have been reported not to accept fish/squid particles as well as *M. rosenbergii*, and tend to become cannibalistic (A. Mangatal, pers. comm. 1998; Herman *et al.* 1999). However, researchers at the UNESP Aquaculture Center (Centro de Aquicultura da Universidade Estadual Paulista), Brazil, obtained PL using *Artemia* plus an egg-custard diet (W. Valenti, pers. comm. 1999); although survival was good until late larval stages, mortality was then very high. The possibility of using live prey whose size would increase with the growth of the larvae could be explored.

For comparative purposes, the larval stage index (LSI), which is the average of larval stage numbers on a specific day, has been plotted against the numbers of days of culture for *M. carcinus* and *M. rosenbergii* (Fig. 21.5). The LSI is similar for both species up to stage IV, reached on the seventh day, but subsequently the LSI increases more slowly for *M. carcinus*. There is pronounced heterogeneity in length, of as much as an order of 5:1, in *M. carcinus* prior to metamorphosis (Herman *et al.* 1999). The first PL appear only after 33 to 56 days; this variability may be related to the temperature at which batches were reared. The low survival (18%) after 45 days in mass production (Herman *et al.* 1999) may be due to cannibalism, which is concentrated between day 15 and day 25 of rearing, as well as larval density. The hatchery technology of *M. rosenbergii* is only partly transferable to *M. carcinus*. More information on the biology, food requirements, and ecophysiological characteristics of *M. carcinus* is needed in order to evolve a reliable protocol for its successful larval rearing and to reduce larval production costs.

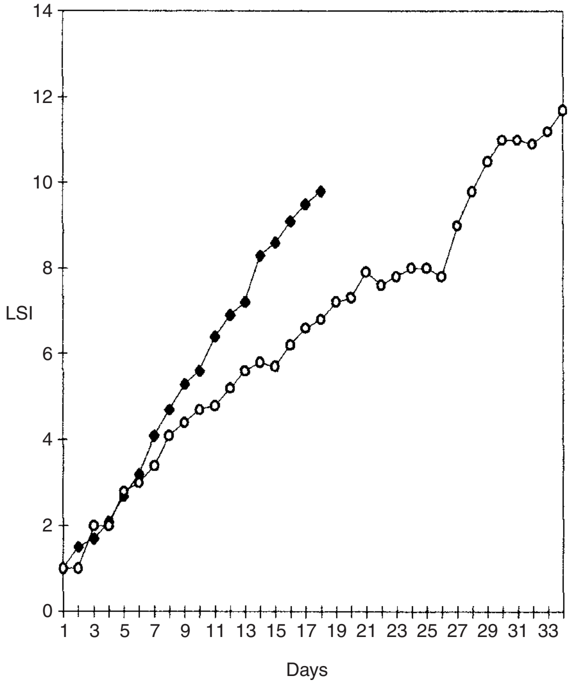

Fig. 21.5 Comparison of larval stage index of *Macrobrachium carcinus* (M.c.) and *M. rosenbergii* (M.r.) at 28.5–30°C. (Source: modified from Herman *et al.*, 1999.)

Key: ■ = Average M.r.; ○ = Average M.c.

21.3.2 Grow-out production

As a result of an adequate supply of PL, two grow-out trials have been conducted in Guadeloupe. Two earthen ponds (100 and 500 m^2) were stocked with 18 and 10 PL (20 mg), respectively. The grow-out schedule (greenwater, 10% water renewal/day, feeding) was the same as for *M. rosenbergii*. The low survival (10 and 12%) was possibly due to the capacity of the prawns to crawl out of the pond. The average estimated production was equivalent to 1.2 t/ha/yr. Growth (length) is similar to that of *M. rosenbergii* in the first 7 months, but at the same length *M. carcinus* is 30% heavier, owing to the weight of its claws (Fig. 21.3). The population structure and the pattern of dominance are similar to those of *M. rosenbergii*. After 14 months rearing, 5% of the population was formed by large males (>100 g) and 15% by small males (<18 g). In order to improve production rates, the provision of shelters for the prawns in the ponds, fencing ponds to avoid prawn escapes, and selective harvesting (culling) seem advisable.

21.4 Amazon river prawn (*Macrobrachium amazonicum*)

Macrobrachium amazonicum is a very important species, which is exploited through artisanal fisheries in the North (Moraes-Riodades 1999) and the Northeast (Dourado 1981; W. Valenti, pers. comm. 1999) of Brazil. This prawn is very abundant in the Amazon region and is well accepted by consumers of all social classes (Moraes-Riodades & Valenti 1999). Fresh, head-on prawns of this species sell at US$ 3.00 to 4.00/kg (W. Valenti, pers. comm. 1999). Some of the catch is even 'exported' to other Brazilian states but, unfortunately, no statistics are available. Brazilian consumers prefer this species rather than *M. rosenbergii* because the taste is stronger and the muscle texture is more rigid (Moraes-Riodades *et al.* 1999).

This species is also used as bait in fishing (McNamara *et al.* 1983) and as a feed in the culture of carnivorous fish (Esteve de Romero 1982). The Brazilian government is stimulating new research efforts on this species, which has an excellent potential to become an important means of promoting social and economic development in the Amazon region with a low environmental impact (Moraes-Riodades & Valenti 1999).

The maximum male size observed has ranged from 110 to 150 mm (Holthuis 1952, 1980) and the maximum female size was reported to be 110 mm (Holthuis 1952).

21.4.1 Seed production

Breeding occurs year-round, with peaks according to various locations and hydrographic systems (Odinetz-Collart 1991). Female size at first maturity has been reported to occur at 33 mm in a Venezuelan lake (Gamba 1997). Guest (1979) observed 195 to 2200 eggs on 2 to 5 g females and reported that first maturity under laboratory rearing conditions occurred at 59 mm, 168 days after hatching. According to this worker, eggs incubate in 12 to 18 days at 30°C and 19 to 24 days at 24°C. It has been observed that the larvae of populations that live near to the coast need brackishwater while other populations that live thousands of kilometres from the sea can complete the larval cycle in freshwater (W. Valenti, pers. comm. 1999). As brackishwater-dependent animals are larger in size, they are under research for aquaculture purposes. Thus, the entire larval cycle of *M. amazonicum* has been completed in both freshwater (Odinetz-Collart 1991) and brackishwater (McNamara *et al.* 1983), depending on the origin of the animals. Studies, performed mainly in Brazil, indicate that the optimal salinity for rearing saline-dependent larvae is 10 to 14 p.p.t. (Guest & Durocher 1979; Barreto & Acioli Soares 1982; Valenti 1985). The fecundity of this species is low, the number of larvae hatched varying from 21 to 2200 per female (Guest 1979; Lobão *et al.* 1986a; Moraes-Riodades *et al.* 1999).

The optimal larval stocking density in the trials conducted by Barreto & Acioli Soares (1982) was 38/L. However, Lobão *et al.* (1987) estimated that a density of 120/L would be economically more feasible. Guest (1979) studied the overall cycle of *M. amazonicum* in the laboratory. According to this author, metamorphosis takes place after eight or nine larval stages in 23 to 26 days at 24°C with a survival rate of 50% (see also Table 21.2). However, Magalhães (1985), working with prawns from a population that completed the larval cycle in freshwater, observed 10 to 11 larval stages in 28 to 33 days until metamorphosis.

Since 1996, PL of *M. amazonicum* have been produced in Brazil (Pará State) at a government hatchery, using technology similar to that practised for *M. rosenbergii* (Moraes-Riodades 1999). Tanks are filled with 12 p.p.t. brackishwater and stocked with 100 larvae/L. The mean productivity has been 40 PL/L after 20 days. Postlarvae have been sold at US$ 4.80/1000.

21.4.2 Grow-out production

Reports of grow-out results with *M. amazonicum* are limited. Coelho *et al.* (1989) stocked 8 PL/m^2 in 100 m^2 ponds and obtained a yield of 245 kg/ha in 6.3 months. Earlier, Coelho *et al.* (1982) observed that PL grew to harvest size (70 mm) in 3 to 4 months. Dourado (1981) stocked juveniles (22–

59 mm, average weight 0.88 g) in 33 m^2 earthen ponds and observed that in 6 months the maximum biomass achieved was about 90 g/m^2; the prawns grew to a maximum size of 110 mm (11 g), but 70% of the population was below 60 mm. Penafort *et al.* (1998) observed that 10-day-old PL stocked in concrete tanks at a density of 10/m^2 under favourable conditions of confinement (optimal temperature and abundant feeding) reached 1.6 to 3.1 g in 104 days. Since 1996, some pilot commercial grow-out projects have been performed in Pará State, Brazil, but results are not yet available (Moraes-Riodades *et al.* 1999).

21.5 Cinnamon river prawn (*Macrobrachium acanthurus*)

The reproduction (Valenti *et al.* 1986), growth and age (Valenti *et al.* 1987, 1989a) of this species in the natural environment have been studied in Brazil. Low aggressiveness, less cannibalistic tendencies than *M. carcinus*, metabolic adaptations to temperature and low oxygen (Dobkin *et al.* 1975; Bernardi 1990), high osmoregulatory capacity (Gasca-Leyva *et al.* 1991; Gonzales-Pena *et al.* 1998), high fecundity (Granados Berber 1984; Valenti *et al.* 1989a), resistance to diseases, and high economic value (Gasca-Leyva *et al.* 1991) suggest that this species may have aquaculture potential, in spite of its relatively small size. Males have been reported to reach 138 mm in 18 months (Valenti *et al.* 1987) and a maximum of 166 mm (Holthuis 1980) to 212 mm (106 g) (Contreras & Campos Lince 1993). Observed maximum female size is 106 to 131 mm (Holthuis 1980; Valenti *et al.* 1987).

21.5.1 Seed production

Breeding occurs in the south of Brazil in the rainy season, December to January (Valenti *et al.* 1986). Fecundity has been observed to average 5500 for 70 to 75 mm females (Granados Berber 1984), while Valenti *et al.* (1989b) observed up to nearly 18 000 eggs. An average of 5500 eggs incubate in 14 days at 27 to 29°C (Martinez Silva *et al.* 1981). Details of the larval development of *M. acanthurus* are included in Table 21.2. Several trials have been carried out, following the hatchery technique used for *M. rosenbergii.* In the experience of two of the authors of this chapter (FH & HLM), the best results are always obtained when the salinity is less than 20 p.p.t. Valenti (1985) recommended 15 to 20 p.p.t. Dobkin *et al.* (1974) obtained 10 to 21% survival and the first PL were observed 29 to 38 days after hatching (salinity 16–18 p.p.t.; temperature 29°C; larval density, stocking rate 5–20/L; fed with *Artemia* nauplii). Figueroa & Gamino (1992) obtained first PL after 29, 48 and 57 days after hatching at salinities of 8, 12 and 30 p.p.t., respectively; the highest survival was obtained at 12 p.p.t. salinity at a larval density of 25/L.

21.5.2 Grow-out production

Published information about grow-out trials with *M. acanthurus* is not recent. Dobkin *et al.* (1974) observed that 15 mm prawns grew to an average size of 86 mm in 4 months, with a survival of 12%. The average size of males was 121 mm and that of females 86 mm. By selecting the largest PL, an average size of 94 mm was obtained, as the proportion of males was higher. In trials in Mexico over a 5-year period, an average production of 1.1 t/ha/yr was obtained (Cabrera Cano 1980). In an unreplicated polyculture trial in Colombia with *Mugil incilis* a production of 210 kg/ha of prawns (average weight 12 g) and 296 kg/ha of fish (70 g) was obtained 133 days after stocking wild-caught prawns (average weight 0.03 g) and mullet (1.8 g) (Martinez Silva *et al.* 1977). Gasca-Leyva *et al.* (1991), noting that *M. acanthurus* has good salinity tolerance, is relatively resistant to diseases and handling, and had achieved a good market size within 6 months in various parts of Mexico, where it had also been reared in polyculture with carps, claimed that it had promising aquaculture potential. However, in spite of the revival of interest in rearing endemic species, particularly in Brazil, there is no progress in the culture of *M. acanthurus* as its larval rearing technology is still problematic.

21.6 Other species

Holthuis (1980) lists 48 species of the genus *Macrobrachium* that are consumed as food and hence economically important. About half of these species have been examined for their potential suitability for aquaculture (Table 21.1). This list has been compiled from published information (e.g. Holthuis 1980; New 1990, 1995; Brown 1991; Jhingran 1991; Jayachandran & Joseph 1992). The major species considered in detail in earlier sections of this chapter are already under commercial or artisanal aquaculture, or are on the threshold of being farmed. Several others are also important, as they are involved in some stage of species selection for aquaculture.

In South and Central America, the Cauque river prawn (*M. americanum*) has potential as a candidate aquaculture species. This species grows to a large size, males reaching a maximum of 250 mm (Holthuis 1980). The prawn contributes to a commercially important fishery in Mexico, Guatemala and El Salvador and its aquaculture potential has been considered high. However, there seems to be no published information on its larval rearing or grow-out culture.

In Africa, from the point of view of its maximum size (189 mm; Marioghae 1987), consumer acceptance, high fecundity (45 000), salinity tolerance (upper salinity tolerance limit 27 p.p.t.), and hardiness, the African river prawn (*M. vollenhovenii*) is believed to have a high potential for aquaculture (Mwangi 1984; Marioghae 1987). In laboratory tests on predation by the prawn it was observed that it can very effectively capture and feed on *Oreochromis niloticus* fry and frog tadpoles, indicating its potential value in polyculture with tilapias, where it would serve as a control on the overproduction and crowding of the tilapias, as well as providing an additional crop (Mwangi 1984). A decade later, the continuing dearth of information on the culture potential of this species was noted by Ajuzie (1994). To this date (1999), no information on the actual production rates in grow-out culture is available, since no trials have yet been reported in the literature. Though some have regarded *M. vollenhovenii* as completing its life cycle in freshwater (M. New, pers. comm. 1999), Willfuehr-Nast *et al*. (1993), examining rearing salinities from 0 to 32 p.p.t., found that 16 to 24 p.p.t. gave the highest survival and growth. Freshwater was reported to be lethal for stage I larvae. The rearing techniques employed were similar to those for *M. rosenbergii*. This finding does not necessarily mean that all *M. vollenhovenii* require brackishwater for larval survival. It is possible that different strains exist, as in the case of *M. nipponense* (section 21.1) and *M. amazonicum* (section 21.4).

It has been claimed that another West African species, the brackish river prawn *M. macrobrachion*, which also grows to a good size (138 mm), has a moderate fecundity (12 000), is hardy and is even more acceptable to the consumer, also has high potential for aquaculture (Kavu 1985; Marioghae 1987). However, Holthuis (1980), giving the maximum size of *M. macrobrachion* as 78 mm, stated that it was less acceptable than *M. vollenhovenii* and was generally (only) consumed by those who caught it from the capture fisheries. Juveniles of both species are abundant in the Niger delta and grow-out trials could easily be carried out, using wild-caught juveniles for stocking purposes.

In Asia, where there is a long and successful tradition of aquaculture, several of the species indicated in Table 21.1, especially the Burma river prawn (*M. birmanicum*), the rough river prawn (*M. equidens*), the Orana river prawn (*M. idae*), the riceland prawn (*M. lanchesteri*), the Dimua river prawn (*M. villosimanus*), and the hairy river prawn (*M. rude*) (Jhingran 1991; Jayachandran & Joseph 1992), could be tested for possible induction into aquaculture. In Thailand, no experiments on the rearing of other species have taken place; work has concentrated on the culture of *M. rosenbergii* (S. Suwannatous, pers. comm. 1998). Experimental trials have already been carried out with *M. lanchesteri* in the Philippines and Malaysia (Johnson 1969; Holthuis 1980), and *M. idae* (Kingston *et al*. 1992a,b) and the Kuncho river prawn, *M. lamarrei lamarrei* (Singh & Qureshi 1997) in India. Even though some of these prawns do not grow to a large size they could very well succeed if a suitable technology is evolved. Considerable research and development efforts are already on-going (Table 21.1). It would be worthwhile if these efforts could be co-ordinated and concentrated on selecting suitable species in an organised manner. Experience with *M. nipponense* in China suggests that small adult (harvest) size is not necessarily a deterrent to commercial culture if the desirable characteristics of the species, especially consumer preference and price, are positive and if the technical hurdles of larval rearing and grow-out are overcome.

Many other research papers on various aspects of the morphology, distribution, larval rearing, physiology, and feeding and nutrition of a variety of *Macrobrachium* species (other than *M. rosenbergii* and the species already dealt with in this chapter) have been published. These have not been cited in this chapter, in which the emphasis has been on developments and practice geared directly towards commercial farming.

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Prawn Capture Fisheries and Enhancement

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This chapter commences by commenting on the official capture fisheries statistics for *Macrobrachium* spp. Following this analysis, the characteristics of the capture fisheries in certain countries, as described in the literature, are supplemented with unpublished information from other sources. Published information on the characteristics of capture fisheries for *Macrobrachium* spp. is sparse, and a considerable proportion concerns the Indian sub-continent, mainly India. In the case of the Indian sub-continent, a considerable proportion of the information comes from papers presented at a single conference (Silas 1992); however, these papers consolidated the results of many pre-1992 studies. Some of these pre-1992 publications were voluminous and there is also a considerable body of 'grey' literature (internal institute reports, etc.). Many papers have been published about the habitat and feeding behaviour of *M. rosenbergii* and other members of the genus under natural conditions. However, these topics are not included in this chapter, which is confined to the scale and characteristics of the fisheries for *Macrobrachium* spp., together with an account of some attempts at enhancement. Where no specific citation is provided for the information provided in this chapter, it has been derived from the questionnaires and personal communications (see the Acknowledgements section of this book), and some of the papers cited in Chapter 17.

While attempting to collate what little information exists for this chapter our main achievement may have been to identify the inadequacy of statistical information and the general lack of scientific studies on these topics. There is a clear need for research in this field, with a view to enhancing the natural fisheries for *Macrobrachium* spp., which are prized by consumers within the countries where they are indigenous and provide significant existing and potential export opportunities. Natural freshwater prawn fisheries tend to be declining, though the effect of this on the market supply has been masked in many countries by the emergence of farmed production during the final three decades of the 20th century. Fisheries enhancement programmes (e.g. in India and Thailand) for freshwater prawns are thought to be beneficial. While no results of these activities have been published in peer-reviewed journals to date (1999), positive benefits in the case of *M. rosenbergii* stocking programmes in Vembanad Lake (Kurup *et al.* 1998) and Kerala (C.M. Nair, pers. comm. 1999) have been noted.

22.1 Statistical information

Capture fisheries statistics for freshwater prawns (Table 22.1) are intermittent, incomplete and probably inaccurate. In the last year for which official statistics are available (1998) the global catch of the giant river prawn *M. rosenbergii* under this category was about 5200 t. Almost all of this total was reported by Indonesia. The Dominican Republic, Brunei Darussalam, Thailand and French Polynesia were the only other reporting countries in 1998. Nearly 5600 t of 'river prawns not elsewhere included' (*Macrobrachium* spp.) were also reported from the fisheries of other countries in 1998, together with over 10 300 t in the Food and Agriculture Organization (FAO) statistical category 'freshwater prawns, shrimps not elsewhere included' (Palaemonidae).

Table 22.1 Nominal capture fishery statistics for freshwater prawns 1989–1998 (metric tons).[a] (Source: FAO, 2000.)

Country	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
	Giant river prawns (*Macrobrachium rosenbergii*)									
Brunei Darussalam	44	20	20	15	11	3	5	14	17	35
Dominican Republic	–	–	–	–	–	–	–	21	…	…
French Polynesia	–	1	–	–	1	+	+	+	3	3
Indonesia	6196	5442	5888	6163	4923	5393	5524	6126	5208	5140
Martinique	–	–	–	–	3	–	–	–	–	–
Thailand	–	97	–	1	–	676	308	4	5	5
Sub-total	6240	5560	5908	6179	4938	6072	5837	6165	5233	5183
	River prawns not elsewhere included (*Macrobrachium* spp.)									
Benin	140	129	118	113	120	139	188	172	165	164
Mexico	2798	1731	2028	2244	4456	3226	4202	4261	3580	3244
USA	14	704	741	445	20	19	19	–	–	–
Brazil	6592	6600	6810	6560	6700	6900	1412	2677	2157	2170
Papua New Guinea	5	5	5	5	5	5	7	7	7	10
Sub-total	9549	9169	9702	9367	11301	10289	5828	7117	5909	5588
	Freshwater prawns, shrimps not elsewhere included (Palaemonidae)									
Egypt	994	1023	2765	1139	2352	3687	3169	2286	2387	2886
Morocco	2	1	1	+	+	+	+	+	+	2
Chile	21	32	5	14	7	5	–	–	–	–
Indonesia	3139	2849	3105	3625	3336	3738	3944	3356	3242	3280
Japan	4235	3917	4544	3667	3987	3382	2717	2572	2413	1872
Philippines	8394	8945	8892	8756	3351	3938	4581	5214	4043	2283
Sub-total	16785	16767	19312	17201	13033	14750	14411	13428	12085	10323
Totals	32574	31496	34922	32747	29272	31111	26076	26710	23227	21094

[a] + = more than zero but less than 0.5 t; – = none or negligible reported; . . . = data not available.

Over the decade to 1998, only six countries reported any fisheries catch for *M. rosenbergii*. Two countries where this species is not indigenous, namely the Dominican Republic and Martinique, occasionally reported some catches during this period. The reasons for this apparent anomaly include the possibility that farm escapes have become established in the fishery, that stolen farmed stock is being sold as 'captured', or that reporting errors occurred.

Statistics for the genus *Macrobrachium* are also reported to the FAO by a further five countries (Table 22.1). Mexico and Brazil reported catches of 3244 t and 2170 t, respectively, in 1998. In neither country is *M. rosenbergii* indigenous and no breakdown between the various indigenous *Macrobrachium* spp. is available. The catch of Papua New Guinea (5–10 t/yr over the decade to 1998) almost certainly consists of the indigenous *M. rosenbergii*. Giant river prawns (*M. rosenbergii*) are not indigenous in the other two countries that have reported a catch of river prawns, namely Benin and the USA. The catch in the USA probably consists mainly of the Ohio river prawn, *M. ohione*, while in Benin it is probably the African river prawn, *M. vollenhovenii*.

A substantial catch of freshwater prawns and shrimps of the family Palaemonidae has been reported to the FAO by a further six countries (Table 22.1) during the decade 1989–1998, although only five reported any catch in 1998. Of these, the only two where *M. rosenbergii* is indigenous are Indonesia and the Philippines. Indonesia reports separate capture fisheries statistics for *M. rosenbergii*, so this species is unlikely to form a part of its return under the FAO category 'freshwater

Table 22.2 Freshwater prawns (*Macrobrachium* spp.) of interest to capture fisheries in Asia and the Pacific. (Source: Holthuis, 1980.)

Scientific name	FAO English name and maximum size (mm) (Male; Female)	Location of fisheries[a]
M. aemulum	Noumea river prawn (Male = 83)	New Caledonia
M. australe	Koua river prawn (105; 77)	Fiji
M. birmanicum	Burma river prawn (315; 147)	Bangladesh, India
M. caledonicum	New Caledonia river prawn (43[b])	New Caledonia
M. choprai	Ganges river prawn (188.5; 130.5)	India
M. dayanum	Kaira river prawn (92; 84)	Bangladesh, India
M. equidens	Rough river prawn (98[b])	India, Indonesia, Philippines
M. esculentum	Sweet river prawn (79[b])	Philippines
M. idella	Slender river prawn (111[b])	India
M. jaroense	Jaro river prawn (72; 62)	Philippines
M. javanicum	Java river prawn (105[b])	India, Indonesia, Malaysia
M. lamarrei	Kuncho river prawn (69[b])	Bangladesh, India
M. lanceifrons	Philippine river prawn (61[b])	Philippines
M. lanchesteri	Riceland prawn (55[b])	Malaysia, Philippines, Thailand
M. lar	Monkey river shrimp (181[b])	Fiji, French Polynesia, Guam, Indonesia, the Marianas Islands, Philippines
M. latidactylus	Scissor river prawn (80[b])	Philippines
M. latimanus	Mountain river prawn (125[b])	Fiji, Marquesas Islands
M. lapidactyloides	Malayan scale prawn (87[b])	Philippines
M. malcolmsonii	Monsoon river prawn (230; 200)	Bangladesh, India, Pakistan
M. mammillodactylus	Knobtooth prawn (137[b])	Indonesia, Philippines
M. mirabile	Shortleg river prawn (40; 60)	Bangladesh, India
M. nipponense	Oriental river prawn (86; 75)	China, Japan, Vietnam
M. pilimanus	Muff prawn (59[b])	Indonesia
M. rosenbergii	Giant river prawn (320; 250)	Bangladesh, India, Indonesia, Malaysia, Pakistan, Papua New Guinea, Philippines, Thailand
M. rude	Hairy river prawn (~130[b])	Bangladesh, India
M. scabriculum	Goda river prawn (70; 62)	Bangladesh, India
M. singantense	Sunda river prawn (66[b])	Indonesia, Malaysia
M. trompii	Forest river prawn (72[b])	Malaysia
M. villosimanus	Dimua river prawn (146; 117)	Bangladesh, India

[a] Examples cited by Holthuis (1980).
[b] Gender not stated; presumably male.

prawns, shrimps not elsewhere included'. However, the substantial catch reported by the Philippines under this category must include an unquantified proportion of *M. rosenbergii*.

22.2 The freshwater prawn fisheries of Asia and the Pacific

Holthuis (1980), summarising the literature up to that date, noted that capture fisheries existed for many *Macrobrachium* spp. in the countries of Asia and the Pacific. Examples of the location of fisheries for the major species are provided in Table 22.2. As noted in the introduction to this chapter, most of the information published about *Macrobrachium* fisheries emanates from the Indian subcontinent, which explains the apparent disparity in the length of section 22.2.2. However, freshwater prawn fisheries are also important in many other countries, notably China. During the preparation of the present book, information on the current importance of various *Macrobrachium* spp. in the local fisheries of Asian and Pacific countries in 1999 was obtained, which is included in this section.

22.2.1 East Asia

The oriental river prawn (*M. nipponense*) is widespread in the natural waters of China. The catch from Lake Taihu has been estimated at 900 to 1000 t/yr. No fisheries enhancement programme was reported but this species is farmed in substantial quantities (see Chapters 17 and 21). Its fishery in Honghu Lake has also been noted (Sun *et al.* 1998). All supplies are consumed domestically.

FAO data (Table 22.1) show that Japan reports an annual catch of freshwater prawns (Palaemonidae), which show a declining trend from a peak of 4544 t in 1991 to only 1872 t in 1998. A high proportion of these prawns are *Macrobrachium* spp.; Japan also includes its production of farmed *M. rosenbergii* under the general category of Palaemonidae in its aquaculture returns to the FAO. Nemoto & Syoji (1995) stated that the annual catch of various *Macrobrachium* spp. from Lake Kasumigaura (north of Tokyo) from 1988 to 1992 averaged 2025 t (range 1614–2536 t). Almost all was *M. nipponense* but, at times, negligible quantities of *M. japonicum*, the Crane river prawn (*M. formosense*) and the Monkey river shrimp (*M. lar*) were also caught. These prawns supply a domestic market and, in 1992, were caught by trawl net (87%), set net (10%) and traps (3%). Experiments on fishways for *M. japonicum* (Hamano *et al.* 1995) and *M. formosense* (Hamano & Honke 1997) have been reported, indicating that these species are of importance in the fisheries of Japan. Evidence of fisheries for *M. nipponense* in Lake Biwa (Yamane 1995) and in Lake Kojima (Kang *et al.* 1995) exists.

There is no fishery for *M. rosenbergii* in Taiwan. An indigenous species is found, for example in the Tungkang river, but it is endangered due to water pollution.

22.2.2 Indian sub-continent

To aid the understanding of this section of our chapter, a sketch map has been provided (Fig. 22.1).

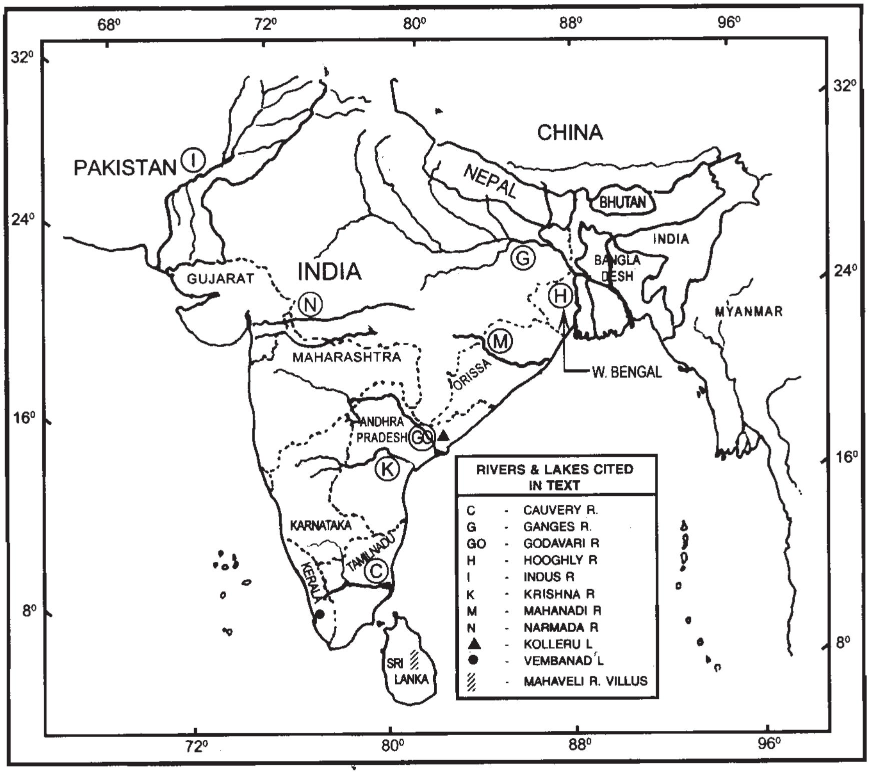

Fig. 22.1 Sketch map of Indian sub-continent. (Source: Methil Narayanan Kutty.)

22.2.2.1 Fisheries

The capture fisheries for freshwater prawns form an important component of total fish production in the sub-continent (Raman 1967; Hettlarachchi & Kularatne 1988; Brown 1991; Jhingran 1991; Tripathi 1992; Akand & Hasan 1992; Yaqoob 1994; A. Matin, pers. comm. 1999). However, since it is an artisanal fishery, dispersed in the expanse of the inland waters of the continent, reliable statistics are unavailable. The total annual freshwater prawn production in India in the early 1990s was estimated as 20000t by Tripathi (1992); this figure included all species and production systems and was likely to be dominated by capture fisheries at that time. Giant river prawn (*M. rosenbergii*) production through capture has been reported to be showing a downward trend in India (Raman 1967; Kurup *et al.* 1992a, 1998; Tripathi 1992; Venketaswamy 1993), but is being compensated for by farmed production (see Chapter 17). Recent estimates of the fisheries for *M. rosenbergii* and the monsoon river prawn (*M. malcolmsonii*) by the Aquaculture Foundation of India indicate a rising trend, from about 1100t in 1993 to nearly 1800t in 1997. While some is consumed within India, 80 to 85% is exported.

In Bangladesh, out of a total production of *M. rosenbergii* of 8073t in 1997/1998, 3723t came from capture fisheries. The total catch of all *Macrobrachium* species in that year, which also included *M. malcolmsonii* and the hairy river prawn (*M. rude*), was over 28000t. The catch is said to have decreased due to the construction of flood control dams, which limited the entry of juveniles into low-lying areas. Hooks, lines and traps are reported to be used to catch freshwater prawns from these areas and from rivers. Details of similar gear used in the Vembanad Lake (India) are provided by Kurup *et al.* (1998). In Bangladesh, large quantities of postlarvae (PL) and juveniles are collected for on-growing in farms (see Chapter 21). It has been estimated that more than 50% of these prawn fry (as well as other species) do not survive. This must have a significant but unquantified effect on the fishery. Very large quantities of the Kuncho river prawn (*M. lamarrei*) and the Burma river prawn (*M. birmanicum*) are also caught in Bangladesh and form an extremely important component of the subsistence catch. *Macrobrachium lamarrei* sell for Tk 15/kg (US$ 0.29kg). These prawns are generally too small to be of interest for export, even when there are processing factories close to the fisheries. Intense fishing activities, both for adults for consumption and for PL and juveniles for culture, have adversely impacted the fisheries. More importantly, the habitat of the prawns has been damaged due to the construction of various flood control schemes. These block river-floodplain access as well as causing a reduction of as much as 30% of the dry season (November–April) river flows. They also cause the loss of as much as 50% of the permanent dry season water bodies. However, no fisheries enhancement programmes for freshwater prawns were reported from Bangladesh.

There is no information on the national production of *M. rosenbergii* in Pakistan, but Yaqoob (1994) reported that about 100t of *M. malcolmsonii* was caught annually from the Indus river. In Sri Lanka, the production of *M. rosenbergii* is based on capture fisheries alone, mainly in the villus (floodplain lake) of the Mahaveli river (Hettlarachchi & Kularatne 1988). Aquaculture activities were suspended and are only just being revived (A.M. Jayasekara, pers. comm. 1998). Brown (1991) indicated that a total of 2000t of freshwater prawns is produced annually in Myanmar.

The major freshwater prawn species in the capture fisheries of the Indian sub-continent are *M. rosenbergii* and *M. malcolmsonii.* In addition, the Ganges river prawn (*M. choprai*), *M. rude*, the slender river prawn (*M. idella*), the Goda river prawn (*M. scabriculum*) and the rough river prawn (*M. equidens*) and several other minor species participate in the fisheries to some extent, depending on the location (Ibrahim 1962; Holthuis 1980; Rajyalakshmi 1980; Jhingran 1991; Kurup *et al.* 1992b; Rao 1992; Tripathi 1992). It appears that the monsoon river prawn, *M. malcolmsonii*, is the most important prawn in capture fisheries (Rajyalakshmi 1974, 1980). This species was reported to constitute about 95% of the riverine prawn fisheries in the early 1960s and made up 15% of total fish production in the Godavari river of India (Ibrahim 1962). A similar situation pertains today. However, in the southwest of India (Vembanad Lake), almost all the production is accounted for by *M. rosenbergii*, the minor components being *M. idella, M. scabriculum* and *M. equidens* (Kurup *et al.* 1992b). *Macrobrachium malcolmsonii* is unrepresented in Vembanad Lake as in several west-flowing rivers of India. *Macrobrachium choprai* forms a minor fishery in the Ganges river; landings at Allahabad, Varanasi, Buxar, Patna, Bhagalpur and Lalgola centres ranged from 5 to 1600 kg/month during the year 1986 (Tripathi 1992).

Tripathi (1992) reported that the annual production of *M. malcolmsonii* in the Hooghly–Malta estuary (West Bengal) averaged 5.05 t (range 0.41–9.82 t) from 1962/1963 to 1965/1966. The corresponding figures for *M. rosenbergii* were 2.27 t (range 1.12–5.58 t), indicating the dominance of *M. malcolmsonii* in the fishery. Most of the fishery (84% of *M. malcolmsonii* and 91% of *M. rosenbergii*) was centred in the upper reaches (the freshwater zone) of the Hooghly estuary. The fishery for *M. malcolmsonii* was active during December to March and August to September, while the *M. rosenbergii* fishery lasted only between August and September. The first- and second-year age groups (represented by modes at 114 and 142 mm for males, and 83 and 127 mm for females, respectively) dominated the fishery for *M. rosenbergii* in the Hooghly freshwater zone. The fishing gears used in the estuary included traps, cast nets, 'bushes' and lights. Kurup *et al.* (1998) provided considerable detail about the various fishing techniques used in the Vembanad Lake (see below).

Ibrahim (1962) stated that the fishery for *M. malcolmsonii* in the Godavari river extended to 800 km up river, but the major fishing centres were Rajamundry, Sironcha and Nanded, 80, 450 and 800 km, respectively, from the sea. The active fishing zones remain the same today. According to Ibrahim (1962), total landings from a stretch of 16 to 24 km at Rajamundry for the years 1959, 1960 and 1961 were 20.4, 36.7 and 35.8 t, respectively, accounting for 14 to 20% of total fish landings. The size of males ranged from 30 to 237 mm and of females from 30 to 197 mm. Three year classes (0, I and II) were represented, but the bulk of the catches were made up of I and II year classes. Rajyalakshmi (1980), comparing *M. malcolmsonii* fisheries in the Godavari and Hooghly rivers, found five year groups in males (48–98, 128, 158, 178 and 198 mm, representing 0 to IV year, respectively) and four year groups in females (63–73, 98, 123 and 143 mm) in the Godavari. In the Hooghly only three male year groups (98, 123 and 133 mm) and two female year groups (75 and 93 mm) were observed. This author concluded that the Godavari fishery is more extensive and abundant and consists of prawns of larger sizes; the maximum sizes observed in this study were 220 mm (male) and 200 mm (female). A record for *M. malcolmsonii* of 243 mm was observed by Venketaswamy (1993) in the Cauvery river of southern India, substantially larger than the maximum recorded by Holthuis (1980). The largest observed by Rajyalakshmi (1980) in the Hooghly was 135 mm. The Hooghly fishery is mainly in the estuarine region whereas the Godavari fishery is confined to the freshwater zone of the river; thus the premise of this comparison was unequal. The gears used in the Godavari fishery are 7 to 26 mm mesh size cast nets and drag nets (7–20 mm mesh). Bait fishing, using a mixture of rice, rice bran and oil cake, is also a common practice. The fishermen ingeniously exploit the local movements of the prawns to shallow waters during dusk and night (Ibrahim 1962).

Tripathi (1992) referred to the existence of distinct fisheries for juvenile freshwater prawns in various river systems in India. The juveniles are used for food, either dried or fresh, and, more recently, for stocking culture ponds. In the Hooghly estuarine system 9 to 30 mm juveniles occur in May to July at Brindaban Chowk on the Roopnarayan and Chakdaha. Juveniles (40–70 mm) occur in September to October at Samudragarh. The PL and early juveniles are caught with fine-meshed cloth and bag nets from shallow canals. In the Mahanadi river *M. malcolmsonii* juveniles occur at Jobra anicut (irrigation dam), Cuttack and also in other rivers in Orissa State. During the peak season 21 to 32 mm juveniles are caught. A maximum of 200 000 juveniles could be caught per night. *Macrobrachium rosenbergii* juveniles have also been located in the lower Mahanadi system at Gobri. In the Godavari river, *M. malcolmsonii* juveniles (26–34 mm) were reported to be caught from the Dowleishwaram anicut during the peak season of December to January (Ibrahim 1962). These are the main sources of prawn seed for aquaculture and also for open water stocking (see section 22.2.2.2). The Andhra Pradesh Department of Fisheries organises daily collections of juveniles that are crowded together in their efforts to climb the anicut walls at Dowleishwaram. Their success in crawling up the moist surface of the walls was recorded by Ibrahim (1962) and was recently personally observed by one of the authors (MNK) of this chapter (Fig. 22.2). In the Krishna river (also in

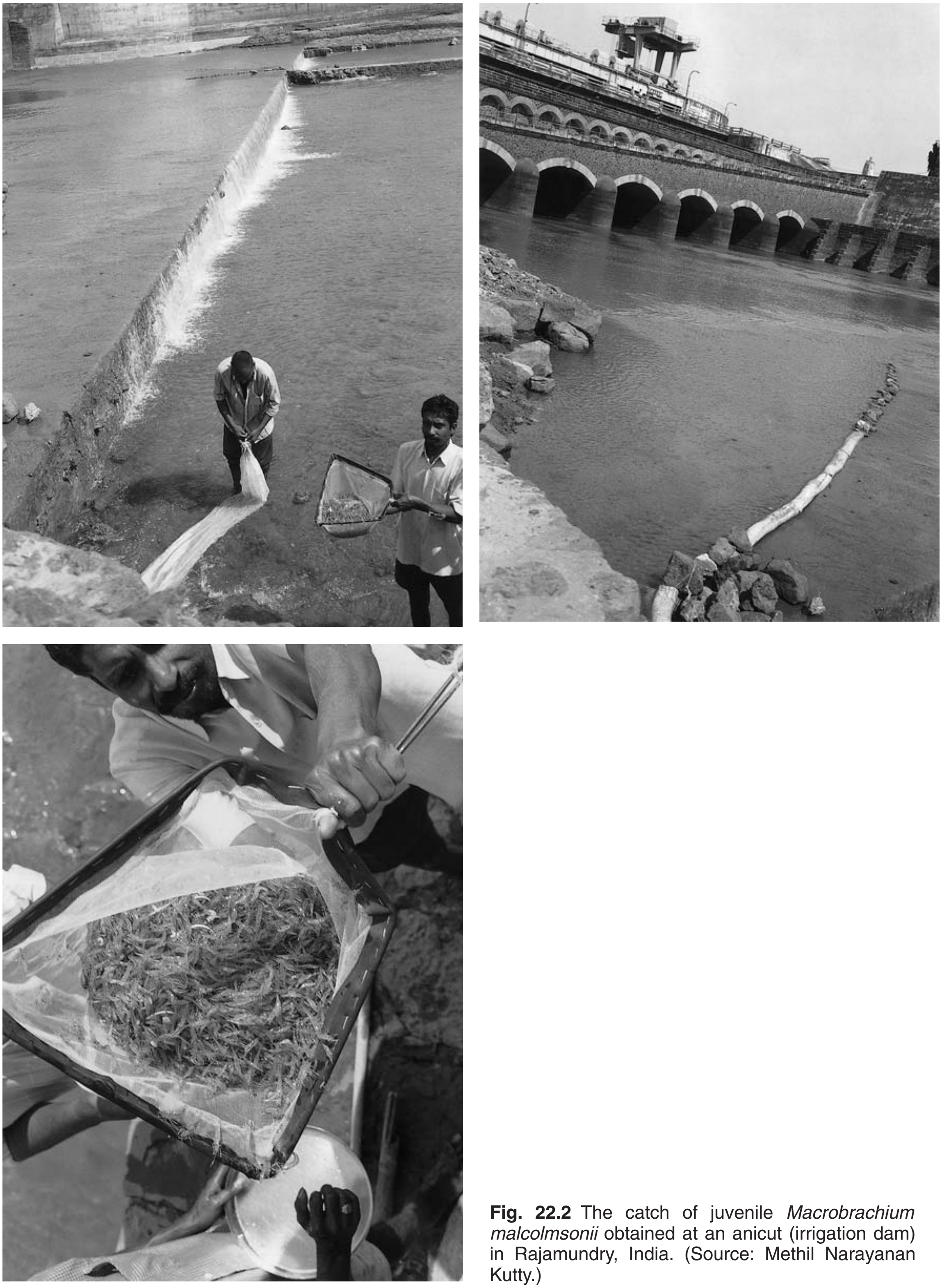

Fig. 22.2 The catch of juvenile *Macrobrachium malcolmsonii* obtained at an anicut (irrigation dam) in Rajamundry, India. (Source: Methil Narayanan Kutty.)

Andhra Pradesh) a juvenile fishery exists near the barrages and anicuts near Vijayawada.

In Kerala, *M. rosenbergii* juveniles are caught in the west flowing Pampa river, which drains into the Vembanad Lake. *Macrobrachium rosenbergii* seeds have also been located in the west flowing Narmada river (Gujarat State). *Macrobrachium malcolmsonii* juveniles occur in large numbers at Jederpalayam in the Cauvery river (Tamil Nadu State), which contributes to an unexploited fishery as a by-catch in fish landings (Venketaswamy 1993). The juveniles that are caught are also regularly stocked in monoculture and polyculture ponds (see Chapter 21).

The fishery for freshwater prawns in Lake Kolleru (Andhra Pradesh) yielded 143 t and 80 t in the years 1978/1979 and 1979/1980, respectively (Rao 1992). Besides the two major species, namely *M. rosenbergii* (35% and 25% of total prawn catch for these two years, respectively) and *M. malcolmsonii* (60% and 49%, respectively), it included *M. rude* (5% and 16%, respectively), *M. scabriculum* (0.2% and 0.6%, respectively), and *M. lamarrei* (0.1% and no data, respectively). The size ranges were: *M. rosenbergii*, 56 to 310 mm (mode, 190 mm); *M. malcolmsonii*, 51 to 233 mm (mode, 130 mm); *M. rude*, 30 to 120 mm (mode, 60 mm) and *M. scabriculum*, 30 to 90 mm (mode, 50 mm). Rao (1992) referred to the serious problem of domestic, agricultural and industrial pollutants entering the lake that, in spite of its access to the sea, have increased enormously, endangering both the prawn fauna and the total ecosystem.

There is a well-established fishery for *M. rosenbergii* in the Vembanad Lake and confluent zones of rivers in Kerala State. Raman (1967) reported that annual prawn landings in Kerala ranged from 189 to 429 t during 1957–1962. In the 20 years following 1962 the fishery declined drastically to an annual yield of only 39 t (Kurup *et al.* 1992a, 1998). This was mainly caused by the construction of the Thanneermukkom barrage/salinity barrier, which separated the lake into a northern saline zone and a southern freshwater zone. This obstructed the downward movement of berried prawns and the upward migration of larvae and juveniles. Kurup *et al.* (1998) observed that only 0.53% of marked (eye-mutilated) and 0.08% of the tagged juveniles released into the downstream region were recovered, and suggested that if some shutters in the dam were permanently kept open a greater recovery of juveniles could be expected. Kurup *et al.* (1992a) found that *M. rosenbergii* males attained lengths of 210, 290 and 330 mm in the Vembanad Lake as they became I, II and III years old, respectively; the corresponding sizes of females were 165, 265 and 290 mm. Kurup *et al.* (1998) estimated the exploited stock of the giant prawn in Vembanad Lake and confluent river systems to be 113 and 129 t for the years 1994 and 1995, respectively, which indicated a 300% increase over the estimate made 5 years earlier, but still one-third of that in the early 1960s. These authors considered that the recent replenishment of the stock was due to several developments. Firstly, there had been a partial change in the operation of shutters in Thanneermukkom dam. Secondly, a low profile enhancement programme had occurred (see section 22.2.2.2). Thirdly, an awareness campaign had been conducted to avoid the catching of undersized and berried females by fishermen. The annual catch of berried females was 23 t, most of which are caught in October (57%); cast nets were the most used tackle, netting 75% of the catch. It was therefore suggested that reducing fishing pressure in October would lead to the conservation of *M. rosenbergii* stock in Vembanad Lake. Kurup *et al.* (1992b, 1998) provided details of the many fishing gears used in the Vembanad Lake. These include:

- cast nets (mesh size range 18 to 38 mm, depending on the specific fishing method; for example, when cast nets are used in combination with baited pits, the mesh size is the largest, namely 36 to 38 mm) which are thrown in areas baited with coconut kernel or boiled tapioca (cassava), the baits being either tied to a longline or broadcast in a location marked by a flagged pole;
- cast nets used in combination with a baited pit;
- semi-spheroid traps made of bamboo splinters used in a baited area;
- trident spears;
- small drag nets operated in conjunction with heaps of brushwood which provide shelters for the prawns; and
- sundry non-selective gears including stake nets, Chinese dip nets, gill nets, hand lines with hooks, and seines.

Cast netting takes place at night (using fluorescent lamps mounted in a canoe), as well as in the daytime.

Macrobrachium idella, as well as *M. rosenbergii*, forms a proportion of the catch marketed from the Vembanad Lake (Kurup *et al*. 1995). Kurup *et al*. (1992b) estimated that *Macrobrachium* spp. constituted 1.63% of total fish production in this lake in 1988/1989. *Macrobrachium rosenbergii, M. idella, M. scabriculum* and *M. equidens* accounted for 38.3, 68.3, 6.8 and 3.3 t of landings, respectively. *Macrobrachium idella* males reach lengths of 75 and 110 mm, and females 70 and 100 mm at the end of the first and second years of their life (Kurup *et al*. 1992a). The fishermen use a special cast net ('Koona chemmeen vala') to catch this prawn.

22.2.2.2 Enhancement

There are only a few cases of artificial recruitment through open water stocking for enhancing natural freshwater prawn fisheries in the Indian subcontinent. None was reported from Bangladesh. Two recent experiences in India, which have already been mentioned in passing in section 22.2.2.1, will be described in more detail here.

According to Harikrishnan & Kurup (1997) and Kurup *et al*. (1998), the annual exploited stock of *M. rosenbergii* from the Vembanad Lake in 1994 was about 112 t. The Kerala State Government is implementing a social fisheries programme (Table 22.3); this includes the enhancement of giant prawn fisheries by stocking the Vembanad Lake, which is connected to the Arabian Sea, and a few selected small reservoirs and rivers in the Kottayam and Alappuzha districts of the State. This stocking programme is believed to have contributed to some improvement in production (Kurup *et al*. 1998; see also section 22.2.2.1). As a consequence of stocking the Murinjapuzha river (Kottayam District), fishing man-days/month have increased from 18–20 days to 29 days; average catch per fisherman has also increased from 2.9 to 3.5 kg/day (S. Kumar, pers. comm. 1999).

The first results of such enhancement programmes cause great excitement. The proud fisherman shown with large prawns (310, 350 and 390 g) in Fig. 22.3 is a member of a 'scheduled caste/scheduled tribe' (SC/ST) fishermen's co-operative society. Assisted by the Deputy Director of Fisheries in Palakkad District, Kerala, this group manages the stocking, harvesting, and sale of its catches from the Kanjirappally reservoir, a small irrigation reservoir close to the home of one of the authors (MNK). The prawns were stocked as PL in January 1999. At first, since *M. rosenbergii* was not indigenous to this water body, the fishermen were not experienced in handling and marketing this species. The first prawns harvested were sold for only US$ 1.40/kg but, recently (early 2000), their value has risen to 3.49 to 4.65/kg. The particular prawns shown in Fig. 22.3 were caught with a wide-meshed gill net in October 1999 and had grown to this size in 10 months.

A programme which is stocking *M. malcolmsonii* juveniles in the upper reaches of the Godavari river, organised by the Andhra Pradesh Department of Fisheries, has been on-going for some years. Details of the capture of juveniles from the

Table 22.3 Details of *Macrobrachium rosenbergii* seed (PL 20) stocked in the rivers and small reservoirs of Kerala State (India) under the social fisheries programme. (Source: Dr C. Mohanakumaran Nair, Kerala Agricultural University.)

	Year of stocking				
District	1992	1997	1998	1999	Place of stocking
Palakkad				690 000	Small reservoirs
Thrissur				400 000	Chalakkudi
Ernakulam	20 000		100 000	12 000	Muvattupuzha
Kottayam		130 000	270 000	200 000	Kumarakom (Vembanad Lake), Murinjapuzha, Thiruvananthapuram
Alappuzha				200 000	Freshwater zone of Vembanad Lake (by March 1999, actual stocking had exceeded 2.4 million)
Kasaragod				400 000	Chandragiri (by March 1999, actual stocking had reached 200 000)

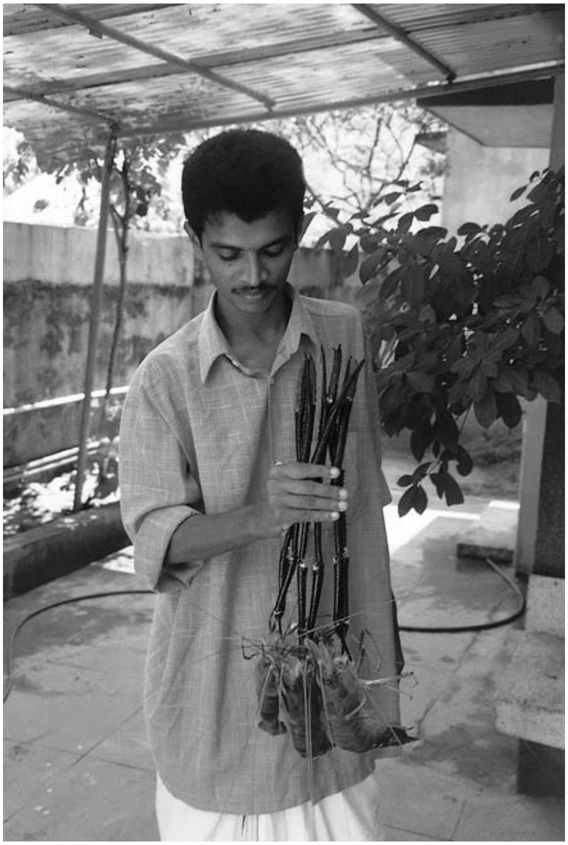

Fig. 22.3 Three prawns (*Macrobrachium rosenbergii*) captured as the result of an enhancement programme in Kerala, India. Note: these prawns had been stocked as postlarvae (PL) 10 months before capture and weighed 310, 350 and 390 g, respectively. (Source: Methil Narayanan Kutty.)

Dowaleishwaram anicut on the Godavari river for the 5-year period commencing with 1994–1995 are given in Table 22.4. A total of 18.6 million juveniles have been collected, of which 9.0 million have been stocked for fisheries enhancement. No information on the effect of this stocking programme is available but this prawn species continues to be a major fishery resource in the Godavari river. A combined monitoring of river stocking and capture fisheries production would be helpful, not only to examine the effect of the stocking programme, but also to formulate future fisheries enhancement activities.

22.2.3 Southeast Asia

Southeast Asia (Fig. 22.4) has been traditionally regarded as the epicentre of *M. rosenbergii* capture fisheries (and, subsequently, aquaculture).

According to the FAO, small quantities of *M. rosenbergii* are captured in Brunei Darussalam (Table 22.1). Enhancement of the fisheries with hatchery-reared PL commenced in 1987 (Sharifuddin & Pudadera 1991) but no report of the efficacy of this programme is available in the literature yet.

Cambodia occupies a strategic position with regard to the fishery for freshwater prawns in the lower reaches of the Mekong river system (Rabanal 1979) and prawns are normally available in local markets. During the preparation of this book it was reported that between 2.5 and 11 t/yr of *M. rosenbergii* had been reported from the capture fisheries of Cambodia between 1993 and 1998. All is domestically consumed but no enhancement programmes have yet occurred. Most are caught from the 2-year fishing 'lot' concessions, which are auctioned and

Table 22.4 Open water collection and stocking of *Macrobrachium malcolmsonii* juveniles (in millions) in the Godavari river, Andhra Pradesh, India.[a]

	1994–95	1995–96	1996–97	1997–98	1998–99[b]	5-year total
Total collected[c]	3.86	4.12	4.24	4.33	2.00	18.55
Stocked in upper reaches[d]	1.79	2.01	2.12	2.81	0.3	9.03
Value (US$)	5952	6000	6071	4333	4857	27213

[a] The juveniles were collected from Dowaleishwaram anicut on the Godavari river. Data obtained from the Department of Fisheries, Andhra Pradesh.

[b] Based on collections made up to 9 December 1998.

[c] All collections reported made by Department of Fisheries, Andhra Pradesh.

[d] Stocked in the upper reaches of the Godavari river.

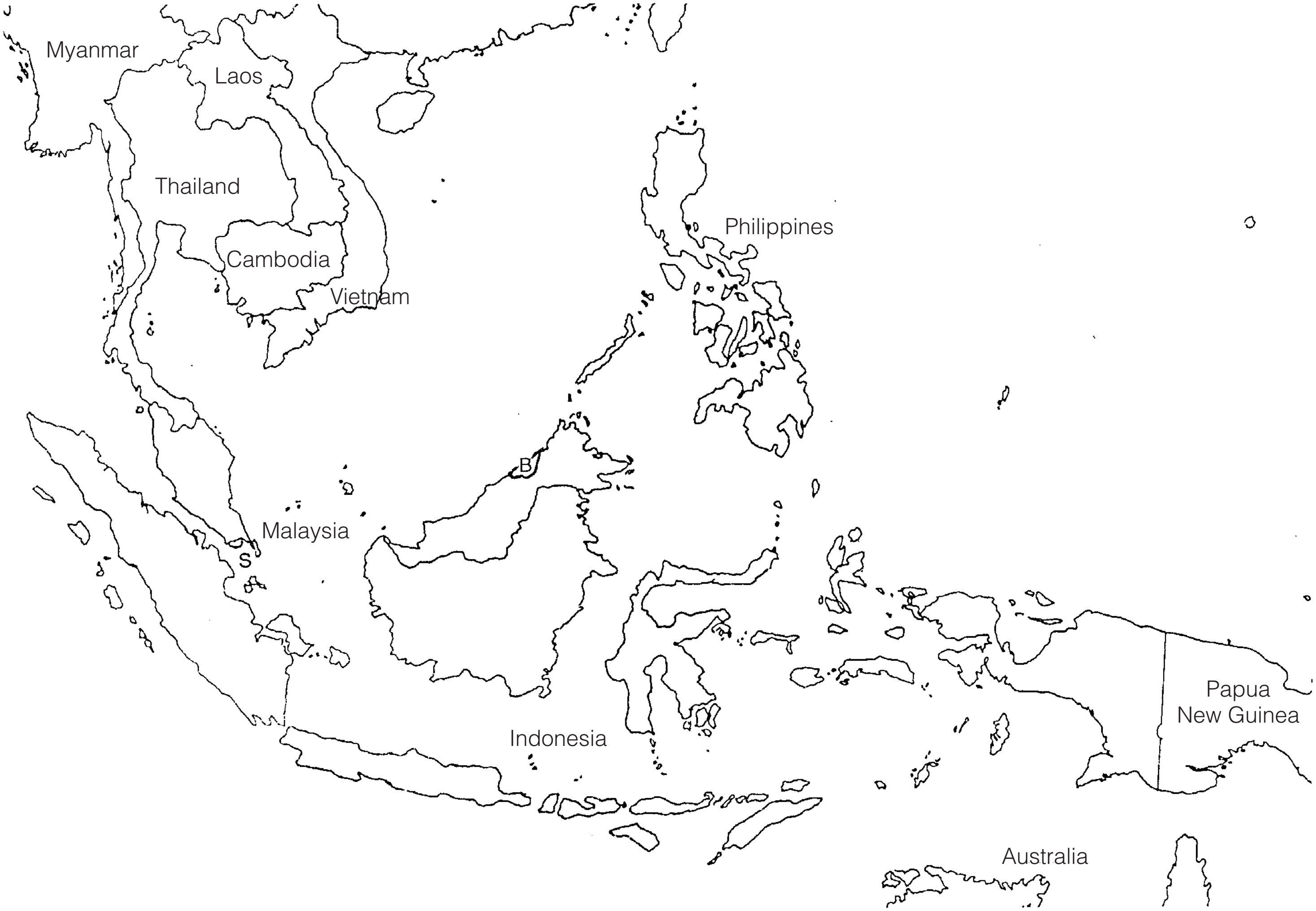

Fig. 22.4 Sketch map of Southeast Asia. (Source: Khun Em-orn, Network of Aquaculture Centres in Asia-Pacific.) Note: B = Brunei Darusallam; S = Singapore.

located in the tributaries of the Mekong river, especially in the provinces of Prey Veng and Takeo.

No recent account of the fishery for freshwater prawns in Indonesia is available. However, Rabanal (1979) reported that it was substantial, as evidenced by the production statistics (Table 22.1); an average of nearly 3400 t/yr of freshwater Palaemonidae were caught over the decade 1989–1998. Fisheries for *M. rosenbergii* exist in most, if not all, provinces of this vast country. For example, Rabanal (1979), noting the results of a study of a 5 million ha project area in Southeast Sumatra, found that at least 1 million ha are under water for part or all of the year, in which *M. rosenbergii* fisheries are extensively exploited. Peak harvesting occurs at the start of the rainy season (June–September), when great numbers float downstream in the form of 'prawn rafts'. Prawns are caught by setting up bamboo barriers in streams as the waters recede, bamboo traps baited with cassava, cast nets thrown in baited areas, and small hooks or shortlines operated from small boats. Small prawns are retained and eaten by the fishers and their families, while the larger ones are kept alive for collectors who purchase selected sizes for sale in local and export markets. Demand (in 1979) was said to be strong, resulting in the establishment of new processing plants. Choice prawns were frozen and exported to Singapore, Hong Kong, Japan, Europe, and North America. Water pollution, the construction of barrier dams, dredging, and lack of conservation regulations were reported to be endangering the freshwater prawn fisheries of Indonesia at that time.

From 1988 to June 1990, 11.7 million PL of *M. rosenbergii* were stocked in selected river systems in Malaysia: 4.1 million in 1988, 5.8 million in 1989 and 1.8 million up to June 1990, to rehabilitate depleted natural fisheries, help inland and inshore fishermen increase their income and to provide additional protein in the diet of Malaysians. According to Singh & Vijiarungam (1992), while actual data are lacking, fishermen have reported improved catches of the prawns, thus indirectly indicating the effectiveness of the programmes. Several rivers are reported (1999) to be well stocked with freshwater prawns, including the Perak, Muda and Rompin rivers. Prawns marketed live in Singapore, being very large (see Chapter 17), are likely to come from the capture fisheries of Malaysia and possibly Indonesia, not from farming. However, landings from the Kelantan river are substantial while prices are low due to the prawns being marketed frozen. The enhancement programme is continuing, with 1 to 4 million government-reared PL being stocked each year. The annual catch of *Macrobrachium* spp. was estimated (in 1999) to be 50 to 150 t annually.

While an economic fishery for various freshwater prawns, including *M. rosenbergii*, in the Philippines was noted by Rabanal (1979), its magnitude was unreported. However, this fishery is very substantial; the Philippines reported a catch of freshwater prawns (Palaemonidae) that averaged over 8700 t between 1989 and 1992 (Table 22.1). However, the fishery appears to be declining. The average catch during the years 1993–1998 was only 3900 t, with nearly 2300 t being reported for 1998. During the preparation of this book, it was reported that *Macrobrachium* fisheries exist (1999) in the Central Luzon and Mindanao river systems, as well as some rivers in the Visayas. A 'symbolic' stocking of *M. rosenbergii* PL into a small farm reservoir in Luzon occurred in 1998, and some prawns are now captured by rice and fish farmers. It remains to be seen if this limited success will be followed up by any significant enhancement programme(s).

Rabanal (1979), recording that 2900 to 4000 t of *M. rosenbergii* and related species was caught during 1965–1973 in Thailand, noted that this quantity was far from adequate to supply domestic demand, let alone fulfil the potential for export. Even at that time, Thailand was known to export *M. rosenbergii* to Malaysia, Hong Kong, Singapore, Japan, the USA, Italy and France. Since the production statistics for freshwater prawns in Thailand are collected from fish markets, where most *M. rosenbergii* now originate from farms, there are no current official data on the capture fishery for this species, despite the occasional returns supplied to the FAO (Table 22.1). In 1974 and 1975, before there was any farmed supply, the national catch in Thailand was recorded as 5743 t and 5561 t, respectively. This catch declined substantially, due to dam construction and pollution. In the 3 years 1996–1998, a catch of only 4 or 5 t have been reported to the FAO (Table 22.1). However, in 1999, one correspondent estimated that about 1000 t/yr of *M. rosenbergii* were being harvested from the capture fisheries of Thailand, mainly due to enhancement programmes. Natural spawning now occurs further inland than it used to, and in orchard canals. This supply, which occurs above the coastal pollution line, is being supplemented by the stocking of hatchery-reared PL. *Macrobrachium rosenbergii* is fished from the four major rivers of Thailand as well as from many reservoirs that have been stocked with PL from government hatcheries. These hatcheries were originally established to stimulate the expansion of farming activities (see Chapter 1) but, now that there are adequate supplies for this purpose from commercial hatcheries, government hatcheries are concentrating on supplying enhancement programmes.

In 1999 it was estimated that >300 million PL/yr are being stocked by the Thai government into the reservoirs, lakes, canals, and rivers throughout the country. Positive feedback has been obtained from these re-stocking programmes, in the sense that high catches have been observed from locations far distant from the coastal area. However, numerical data are sparse or non-existent. In two reservoirs, records of returns from stocking programmes have been kept. Data from the Ubon Ratana reservoir show an increased catch since stocking began. One and a half million PL were stocked in 1996, 4.1 million in 1997, and 7.0 million in 1998. The recorded catch, which almost certainly underestimated total production, was 167 kg in 1996, 254 kg in 1997 and 316 kg in 1998. Similarly, in Pak Mun reservoir, 6.0 million, 5.7 million and 7.9 million PL were stocked in 1996, 1997 and 1998, respectively, while the catch expanded from 7.3 t in 1996 to 14.5 t in 1997 and was 11.8 t in 1998. Prawns are caught for family consumption and for sale. The price for wild-caught *M. rosenbergii* is reported to be higher than for farmed animals. No wild-caught prawns are exported. Small quantities of the riceland prawn (*M. lanchesteri*) are harvested for family use in the rice fields, reservoirs and canals of Thailand.

Freshwater prawns (*M. rosenbergii* and probably other *Macrobrachium* spp.) are certainly an important component of the capture fisheries of Vietnam, particularly in the Mekong delta region. However, it is particularly difficult to estimate how much of the total production is farmed and how much originates from the fishery. FAO aquaculture data (see Chapter 1) indicate a substantial production of farmed freshwater crustaceans in Vietnam, which had reached 25 600 t in 1998. However, as discussed in Chapter 17, it is difficult to know what proportion of this estimate consisted of *M. rosenbergii*, or to be sure that it does not include production from the capture fishery. To date, no data on the capture fishery for freshwater prawns (*Macrobrachium* spp.) or Palaemonidae have been reported to the FAO. However, during the preparation of this chapter in 1999, it was estimated that 3000 to 5000 t/yr of *M. rosenbergii* were being caught in the Mekong delta region of Vietnam, primarily from rivers but also from lakes and reservoirs. Trawl nets, set nets, stow nets, cast nets, hook and line, and traps are used for this purpose. Most of the production from prawn fisheries in Vietnam is directly sold to prawn collectors or sold in the local markets; in both cases the prawns are sold alive. Ultimately, more than 50% of the catch is exported. No enhancement programme has yet commenced (1999).

22.3 The freshwater prawn fisheries of Oceania

Although there is no commercial fishery for *M. rosenbergii* (commonly known as the 'cherabin') in Australia, freshwater prawns are commonly caught for a meal during camping, or as bait for barramundi (*Lates calcarifer*) fishing. Towards the end of the rainy season it is not difficult to catch sufficient for such purposes with a cast net (C. Lee, pers. comm. 1999). Massive migrations of juveniles, on one documented occasion estimated at 500 to 1000 million, occur every year during the heavy rainy season in the rivers (e.g. Daly, Roper) of the Northern Territory. Similar migrations have been observed towards the end of the wet season in the Fitzroy and Ord rivers of the northern part of Western Australia (Anonymous 1997).

Macrobrachium lar is endemic to the rivers of Guam but is only caught for personal use and in very small quantities. *Macrobrachium* spp. are reported to be speared and sold at the roadside in the Solomon Islands; it seems that these are both *M. rosenbergii* and *M. lar*.

A fishery for *M. rosenbergii* exists in Palau (Rabanal 1979). No capture statistics, or commercial freshwater prawn fishing activities are reported from Hawaii.

22.4 The freshwater prawn fisheries of Africa

Several species of *Macrobrachium* have been reported to be of economic importance in the capture fisheries of Africa (Table 22.5).

According to Gordon (1989), the freshwater prawn fishery in Ghana is based on *M. felicinum*, *M. raridens*, *M. macrobrachion*, and *M. vollenhovenii.* Immature *M. vollenhovenii* are fried and sold by roadside vendors near the huge Volta dams (Brown 1999).

During the preparation of this book, capture fisheries production was reported from Mauritius. Very small quantities of freshwater prawns, mainly the Monkey river prawn (*M. lar*), but also the Koua river prawn (*M. australe*) and *M. hirtimanus*, are said to be poached on private land. The river fishery for *M. lar* is said to have declined (1999) due to pollution and over-fishing. No enhancement programme for indigenous *Macrobrachium* spp. has occurred but *M. rosenbergii* has been stocked into privately owned reservoirs since 1996.

Enin (1995) reported that a catch of mixed species in Nigeria, which was 66% *M. macrobrachion* but also included *M. vollenhovenii* and *Penaeus notialis*, fetched only US$ 0.25/kg when landed by canoe.

22.5 The freshwater prawn fisheries of the Americas

Records in the literature prior to 1980, as summarised by Holthuis (1980), noted that capture fisheries for several *Macrobrachium* spp. existed in Latin America and the Caribbean, either for human consumption or for bait. Examples of the location of fisheries for the major species are provided in Table 22.6. Weidner *et al*. (1992) stated that the only important fishery for *Macrobrachium* spp. of commercial importance was in Brazil, where catches declined from 10 100 t in 1985 to an estimated 7300 t in 1989. Since the records of Holthuis (1980) and Weidner *et al*. (1992), the first record of the Amazon river prawn (*M. amazonicum*) in Argentina has been published (Pettovello 1996). However, no fishery for this species there was noted; previously the furthest south it had been observed was in the Rio Apa of Paraguay.

During the preparation of the present book, the capture of various *Macrobrachium* spp. for local consumption was specifically reported in several Latin American countries in 1999. For example, fisheries for the Cinnamon river prawn (*M. acanthurus*) were reported in Brazil (mainly in the Amazon rivers and the semi-arid Northeast, but also in the rivers of the Southeast), Colombia (in

Table 22.5 Freshwater prawns (*Macrobrachium* spp.) of interest to capture fisheries in Africa. (Source: Holthuis, 1980.)

Scientific name	FAO English name and maximum size (mm) (Male; Female)	Location of fisheries[a]
M. australe	Koua river prawn (105; 77)	Madagascar
M. dux	Congo river prawn (55; 30)	Zaire; Nigeria (Marioghae 1987)
M. idae	Orana river prawn (110[b])	Madagascar
M. idella	Slender river prawn (111[b])	Tanzania
M. lar	Monkey river shrimp (181[b])	Mauritius
M. lepidactylus	Madagascar scale prawn (52)	Kenya, Madagascar, Tanzania
M. macrobrachion	Brackish river prawn (78[b])	Benin, Liberia, Guinea; Nigeria (Kavu 1985; Marioghae 1987; Enin 1995)
M. patsa	Patsa river prawn (72[b])	Madagascar
M. raridens	Volta river prawn (~150[b])	Ghana, Guinea
M. rude	Hairy river prawn (~130[b])	Kenya, Tanzania
M. scabriculum	Goda river prawn (70; 62)	Kenya, Tanzania
M. vollenhovenii	African river prawn (182[b])	Côte d'Ivoire, Gabon, Guinea, Liberia, Senegal, Zaire; Nigeria (Marioghae 1987; Mwangi 1984; Enin 1995)

[a] Examples cited by Holthuis (1980), except where otherwise noted.
[b] Gender not stated; presumably male.

Table 22.6 Freshwater prawns (*Macrobrachium* spp.) of interest to capture fisheries in the Americas. (Source: Holthuis, 1980.)

Scientific name	FAO English name and maximum size (mm) (Male; Fermale)	Location of fisheries[a]
M. acanthurus	Cinnamon river prawn (166; 110)	Brazil, Mexico, Venezuela
M. amazonicum	Amazon river prawn (150[b])	Brazil, Guyana, Suriname, Venezuela
M. americanum	Cauque river prawn (250; 193)	El Salvador, Guatemala, Mexico
M. carcinus	Painted river prawn (233; 170)	Brazil, Curaçao, Dominica, Mexico, Puerto Rico, Suriname, Venezuela
M. heterochirus	Cascade river prawn (135; 73)	Brazil
M. jelskii	Agar river prawn (56[b])	Brazil
M. ohione	Ohio river prawn (68; 102)	USA
M. olfersii	Buchura river prawn (90[b])	Brazil, Venezuela
M. tenellum	Longarm river prawn (150[b])	El Salvador, Mexico

[a] Examples cited by Holthuis (1980).
[b] Gender not stated; presumably male.

the Ciénaga del Totumo and Sierra Nevada de Santa Marta regions), Guadeloupe, Martinique, and Mexico. In Mexico, the *M. acanthurus* fishery is substantial, contributing some 50% of the capture fisheries output of freshwater prawns, which was reported to have totalled between 3300 t and 4600 t in the years 1993–1998.

FAO statistics showed a catch of *Macrobrachium* spp. in Brazil averaging nearly 6700 t/yr (range 6560–6900 t) between 1989 and 1994 (Table 22.1). However, this declined to an average of about 2100 t/yr from 1995–1998 (range 1412–2677 t). Local correspondents similarly reported that the catch from *Macrobrachium* fisheries in Brazil had averaged nearly 2400 t/yr (range 1620–2932 t) in the years 1993–1998. One observer states that both these sets of figures may be underestimates and that true production may be as much as twice as great (W. Valenti, pers. comm. 2000). About 85% of the total freshwater prawn fishery is comprised of *M. amazonicum* but *M. acanthurus* and *M. carcinus* are also regularly caught. All are caught by artisans (Figs 22.5a and 22.5b) and consumed domestically. *Macrobrachium amazonicum* is very abundant in Pará State in the Amazon region of Brazil and is well accepted by consumers (Moraes-Riodades 1999; Moraes-Riodades & Valenti 1999). The scale of the fishery for this species is significant in the rivers of the Amazon and in the lakes and reservoirs of the semi-arid region of Northeast Brazil. There is an important market in the capital of Pará State, Belém, and other nearby cities. *Macrobrachium amazonicum* is preferred to *M. rosenbergii* because of its stronger taste and more rigid texture (Moraes-Riodades *et al*. 1999). In late 1998 this species was selling at US$ 3.0 to 4.9/kg (fresh, head-on). 'Mushiness' does not seem to be a problem with this species, even though it is not killed by chilling. Recently (1999), some experiments on its hatchery rearing, using similar techniques to those for *M. rosenbergii*, are expected to lead to further studies on *M. amazonicum*. The fishery for *M. amazonicum* has not been quantified but must be very significant in volume. Several metric tons have been seen to be delivered to a single market in one day and many hundreds of artisanal fishers sell them at the roadsides (W. Valenti, pers. comm. 1998). This species is also transported from the Amazon region to other Brazilian states (Moraes-Riodades 1999). *Macrobrachium amazonicum* is sold live or fresh in large fish markets adjacent to tourist beaches, and alongside the roads in the Amazon region; in the semi-arid Northeast it is preserved with salt and sold in many open-air markets.

Fisheries for the Cauque river prawn (*M. americanum*) are currently reported in Colombia, Costa Rica, Mexico (5% of the total freshwater prawn fishery), and Peru. In the Pacific watersheds of Colombia this species, known as 'muchilla', is reported to constitute an important year-round fishery and the production is increasing. It is estimated that the average annual production is 600 t. About 70% is sold fresh; some are transported to

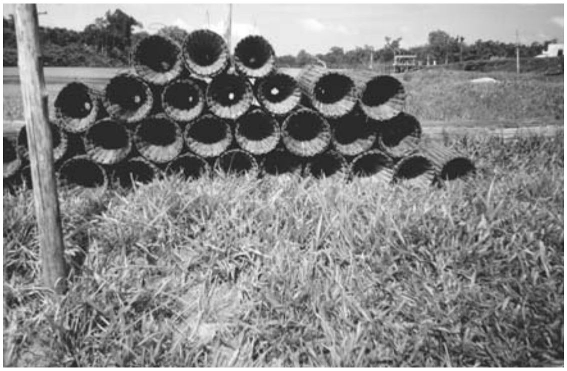

Fig. 22.5a A fishery trap ('matapi') used in the Amazon region of Brazil for capturing *Macrobrachium amazonicum*. Note: each fisherman uses about 60 of these traps at the same time. (Source: Patricia Moraes-Riodades.)

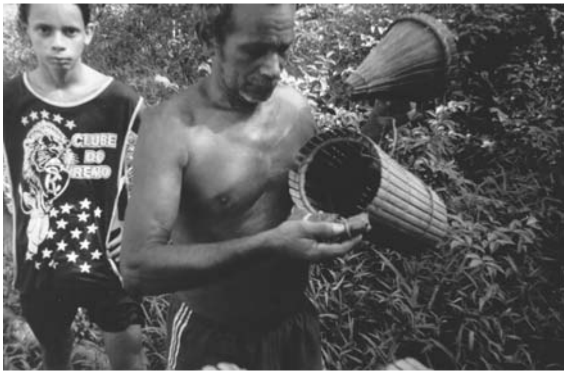

Fig. 22.5b Detail of the 'matapi', Brazil. (Source: Patricia Moraes-Riodades.)

market places, where they are frozen and thawed and later sold as 'fresh'.

Macrobrachium carcinus (painted river prawn) fisheries were noted by correspondents in Brazil (mainly in the Amazon rivers and the semi-arid Northeast, but also in the rivers of the Southeast), Colombia (in the Ciénaga del Totumo and Sierra Nevada de Santa Marta regions), Costa Rica, French Guiana (where they were being sold for US$ 20/kg in 1999), Guadeloupe (estimated at 3 t/yr), Jamaica (which may have been amalgamated with the farmed production of *M. rosenbergii*, thus explaining the apparent statistical discrepancy noted in Chapter 17), Martinique, Mexico (25% of the total freshwater prawn fishery), and Puerto Rico. However, the fishery in Cuba is said to insignificant. One of the authors (MBN) of this chapter observed *M. carcinus* being caught by coconut-baited traps when working in Dominica in 1977. A project for re-stocking *M. carcinus* in the rivers of Guadeloupe was mentioned by one correspondent who also noted problems in river management, due to pollution and human predation. Although no enhancement programme was recorded in Brazil the need for such activities is recognised, to counteract the declining fisheries for both *M. carcinus* and *M. amazonicum*. No other enhancement programmes were reported in Latin America and the Caribbean.

Fisheries for a number of other *Macrobrachium* spp. were also reported, including *M. crenulatum* and *M. faustinum* in Guadeloupe and Martinique, *M. heterochirus* (Cascade river prawn) in Guadeloupe, *M. inca* in Peru, and *M. tenellum* (longarm river prawn) in Mexico (20% of the total freshwater prawn fishery). *Macrobrachium rosenbergii*, which are occasionally sold by roadside vendors in Puerto Rico, are claimed to be from the natural fishery but are probably purchased from farmers. None has been observed in the rivers during sampling by local university staff and it is thought that the giant river prawn would not be able to compete with the indigenous *M. carcinus*. Interestingly, a small fishery for *M. rosenbergii* has been noted in the Espírito Santo and Pará States of Brazil, from a population that appears to have become established following escapes from culture ponds (see Chapter 23). Several correspondents indicated that there were no *Macrobrachium* fisheries in their country; this indicates that there is no 'commercial' or 'significant' fishery but does not necessarily mean that no freshwater prawns are caught for domestic consumption or local sales. Only one species, the Ohio river prawn (*M. ohione*), was reported by Holthuis (1980) to be of economic importance in the fisheries of continental USA (Table 22.6).

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23

Sustainability of Freshwater Prawn Culture

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The urgent need to increase the global supply of finfish, molluscs and crustaceans through the expansion of aquaculture activities, in the face of finite supplies from capture fisheries, has been well documented during the 1990s (e.g. New 1991; Hempel 1993; FAO 1997c; New 1997, 1998, 1999b; FAO 1999; Pedini 1999). During that decade the related topics of aquaculture sustainability and responsible aquaculture increasingly became major concerns and were the subject of numerous publications, conferences, and workshops (e.g. Csavas 1993; Reinertsen & Haaland 1995; ADB/NACA 1998; FAO 1998; IFS 1998; Svennevig *et al.* 1999; Shehadeh 1999). The Food and Agriculture Organization (FAO) Code of Conduct for Responsible Fisheries (FAO 1995) was published and contained a specific section (Article 9) on aquaculture; aquaculture was also included in several other sections of the code (CCRF). The publication of the CCRF was followed by a series of specific technical guidelines for responsible fisheries, including aquaculture (FAO 1997a). The Holmenkollen guidelines for sustainable aquaculture were also drafted (Reinertsen & Haaland 1995) and revised to take account of the CCRF (Svennevig *et al.* 1999).

During this period, the private sector increased efforts to promote aquaculture sustainability itself and to utilise it as a marketing tool. These included the preparation of codes of practice and conduct (e.g. Anonymous 1999a; Boyd 1999; Fegan 1999) and moves towards the promotion of 'organic aquaculture' (Laird 1999a). Discussions about the nature of various aquaculture product certification schemes commenced (e.g. Banks 1998; Anonymous 1999b; Laird 1999b). The need for aquaculture to cultivate its public image in the face of mounting criticism became urgent at this time (New 1999a).

This chapter is an examination of the management practices of freshwater prawn farming, which is intended to stimulate discussion about whether it fits within this new aura of responsible and sustainable aquaculture. The major advantages and disadvantages of the culture of *Macrobrachium rosenbergii* are discussed in a qualitative manner. As yet, there are insufficient data to quantitatively evaluate the social and economic benefits of this form of aquaculture, compared to alternative uses of the resources that it requires (either for aquaculture or other purposes).

23.1 Environmental and social benefits of freshwater prawn farming

Competition for space and other resources is often much more severe in coastal than inland areas. Coastal aquaculture not only has to compete with many other industrial, maritime, urban, recreational and tourism activities but may have serious social and environmental consequences if not practised responsibly. For example, serious concerns (sometimes real but often inaccurate, exaggerated, and biased) have been previously expressed about the destruction of mangrove communities by marine shrimp farming. Freshwater prawns are normally reared inland; therefore, this form of aquaculture neither competes for coastal resources nor harms coastal eco-systems. Site selection is probably the most important factor influencing sustainability;

freshwater prawn farming presents more flexibility in selection. In contrast to marine shrimp farming practices, freshwater prawn culture would have less of a tendency to conflict with or displace other activities. Freshwater prawn farming is also more easily integrated into the existing landscape.

The vast expansion in the production of farmed marine shrimp that occurred during the last two decades of the 20th century was fuelled primarily by the global market for this commodity in developed countries, principally Europe, Japan, and North America. Production provided the opportunity of increased foreign exchange earnings for many developing countries. Their governments, and international organisations, seized upon this attractive opportunity as a means of creating wealth and employment. In particular, the allure of marine shrimp farming attracted considerable local and foreign private investment in tropical countries. Some investors have shown little or no appreciation for the sustainability of marine shrimp farming. This behaviour prevailed because marine shrimp farming created rapid returns on investment and 'worked-out' areas could be abandoned with ease. The lack of concern of this minority produced severe social and environmental problems in many countries. Such negative effects damaged not only the potential for shrimp farming but also the reputation of aquaculture in general. The attitudes of social workers, environmentalists, and consumers, in addition to the concerns of international organisations, led to the development of the previously mentioned codes of conduct and practice that have profoundly affected the industry.

Freshwater prawn culture has escaped the attention of those concerned with environmental and social issues. This 'oversight' is not due to its small scale compared with that of marine shrimp farming, but rather that its ecological impact is not recognised to be threatening. Freshwater prawn farming is less likely to have a detrimental impact because prawns cannot be reared at densities as high as those commonly used in marine shrimp farming. As a result, productivity is generally lower, management is less labour intensive, and the potential for the abuse or waste of resources is minimal. Specific negative effects of *M. rosenbergii* culture on the environment have yet (2000) to be documented. Nonetheless, some inherent dangers (see section 23.2) need to be addressed to ensure that this form of aquaculture continues to be practised responsibly.

The key to ensuring the sustainability of freshwater prawn culture is achieving the most efficient use of the available resources while making sure that the environment is not altered or compromised. The comparatively lower densities associated with freshwater prawn farming relative to marine shrimp farming allow for a greater contribution of natural productivity towards satisfying nutrient requirements. Maximising the contribution of natural productivity, even through some organic fertilisation practices, will generally result in considerable savings in feed costs, thereby decreasing the amount of operational costs. The use and control of natural productivity as part of the practices for nutrient provision in pond culture is definitely an important contributor to sustainability. Moreover, the omnivorous nature of freshwater prawns provides more flexibility in the selection of feed ingredients, due to a greater capacity for digestion of different nutrients. Optimising feed efficiency while reducing feed costs has a greater potential in freshwater prawn than in marine shrimp farming. In addition, there is good evidence that fish meal or other marine proteins can be eliminated in diets for freshwater prawns. This possibility is less likely for the species of marine shrimp that are intensively cultured. Reducing the dependency on fish meal will avert the increasing demand by aquaculture for the limited amount of quality fishmeal available.

The control of ovarian maturation and spawning has been a chronic problem in the marine shrimp farming industry. Freshwater prawn farming has not been confronted with this dilemma. Closure of the reproductive cycle is an important component of aquaculture sustainability, eliminating the need for the capture of wild broodstock and the accompanying seasonality of production. Dependency on natural stock does not provide the regularity in supply and quality that can only be achieved through the operation of efficient and successful hatchery operations. Ovarian maturation and spawning of freshwater prawns occurs in captivity without any special manipulation of environmental conditions.

In an attempt to avoid criticism of the social and environmental consequences of its activities in coastal areas, and to increase the areas available for this form of aquaculture, the culture of marine shrimp in inland ponds at reduced salinities became fashionable in some countries during the last half of the 1990s. This practice occurred in either specially constructed ponds or existing fish or freshwater prawn ponds. However, this trend became the subject of environmental concern because of the danger that an increase in soil salinity might affect the potential of these and adjacent areas for other forms of agriculture. The practice was eventually banned in Thailand and many areas were returned to finfish or freshwater prawn farming, or to agricultural (mainly rice farming) use. Prawn farming is preferable to marine shrimp farming in inland areas because saline water is not required once prawns have metamorphosed from the larval stages. A large proportion of marine shrimp farming is either extensive or intensive. Both these extremes have a greater requirement than semi-intensive systems for certain resources. High-density culture also increases the potential for environmental pollution through the discharge of soluble and solid wastes. Freshwater prawn farming is ideally suited to semi-intensive technology (see Chapter 10).

The use of *M. rosenbergii* in polyculture and integrated crop and livestock production has been discussed in Chapter 12; it is obvious that freshwater prawns are more suitable than marine shrimp for these forms of tropical aquaculture. Recently, using Arizona as a target area for consideration, *M. rosenbergii* has been suggested as a potential candidate for integration with irrigated agriculture systems within arid farming regions (Brooks 1998).

Some attempts to market the freshwater prawns grown in temperate areas of continental USA as ‘more environmentally acceptable products’ than the products from the domestic farming of marine shrimp have been suggested (see Chapter 11). While such attempts to stimulate freshwater prawn farming in these or other temperate regions may be laudable, it is important that such campaigns have a sound economic basis. The encouragement of one form of farming at the expense of another would be imprudent without establishing that it is a more responsible form of aquaculture and profitable for those who invest in it. Ultimately, success is based on a matrix of site-specific factors, which include climatic suitability, resource availability, consumer acceptance, marketing tactics, and technical competence. This applies to freshwater farming in both tropical and temperate climates. For example, the economic feasibility of rearing oriental freshwater prawns (*M. nipponense*) in China (see Chapters 17 and 21) is based on a set of factors that are very different to those that apply to the culture of *M. rosenbergii* in the southern States of the USA.

Marine shrimp farming and freshwater prawn culture are not mutually exclusive. There are opportunities for the expansion of both types of aquaculture. The expanding global market for marine shrimp that has appeared due to increasing affluence, and the limited supplies available from the capture fisheries, have fuelled investment in farming. Presently (1999), the market for freshwater prawns is becoming more globally oriented (see Chapters 17 and 19). However, except in a few countries (see Chapter 22), supplies of prawns from the inland capture fisheries are negligible and unlikely to increase. Arguments presented in this section indicate that freshwater prawn farming is more amenable to the development of ‘environmentally correct’ technology. These advantages provide opportunities for freshwater prawn farmers to expand their market for a unique product that would compete well with marine shrimp.

In addition to those opportunities that are likely to attract private investment in medium- and large-scale farms, freshwater prawn farming is a highly suitable candidate for inclusion in government policies and programmes designed to promote sustainable rural development. *Macrobrachium rosenbergii* can be farmed at various levels of technology. Some farms may be operated by commercial enterprises and accordingly generate significant income and employment. Others may be very small, family-operated units which primarily enhance family income and the local economy. The cultivation of indigenous freshwater prawns (whether *M. rosenbergii* or other *Macrobrachium* spp.) is particularly attractive for development programmes. These may include the production of postlarvae for re-stocking purposes, thus benefiting rural riverine and lakeside populations, in addition to supplying prawn farms. Such activities, involving *M. amazonicum*, have recently been proposed as a rural development programme for the Pará State of Brazil (Moraes-Riodades

1999). In many tropical developing countries, marine shrimp farming is controlled by a relatively small number of entrepreneurs (whose involvement may be ephemeral) and its products are mainly exported. In contrast, freshwater prawn farming is particularly well-suited to small long-term family businesses, can be practised by relatively unskilled fishing and rural people, generates products that may be consumed by all social classes, and is amenable to integration with crop production.

23.2 Areas of concern

Certain aspects of *M. rosenbergii* culture, which are also common to other forms of aquaculture, have inherent dangers. The main areas for concern include: the practice of rearing prawns in domestic effluents that occurs in some countries; the widespread introductions of *M. rosenbergii* into regions where it is not indigenous; and pollution caused by discharge water.

Tripathi (1990) noted that the milieu of raw sewage-fed ponds in the Calcutta area was highly conducive to the culture of *M. rosenbergii* but that social stigma and the possible transmission of pathogenic diseases by this technique were constraints. Culture in treatment ponds may be more acceptable. In India, the culture of prawns in domestic wastewater ponds is a relatively new concept and has begun in only a few places, such as West Bengal. Ali *et al*. (1993) described this type of aquaculture as technologically advanced and becoming more profitable in developed as well as developing countries. These authors reported that prawns grew rapidly in a secondary oxidation pond, strongly indicating that biologically treated domestic sewage offers excellent opportunities for its culture without any supplementary feeding. Aquaculture may have a role in the recycling of nutrients from wastewater. Low cost, easy to maintain, symbiosis of prawn culture in waste stabilisation ponds is claimed to be very promising. However, the products of such farming techniques are unlikely to be acceptable to international consumers or meet the requirements of any eco-labelling procedure.

Macrobrachium rosenbergii is an exotic species in most of the countries where it is farmed. Generally, the escape of introduced species into natural waters can result in two types of negative ecological impacts: the dissemination of new pathogens and the establishment of an exotic population that negatively impacts the population of a native species (competition, predation, etc.). There is no information concerning the dissemination of pathogenic micro-organisms by *M. rosenbergii*. The introduction of *M. rosenbergii* is less likely to cause negative impacts on indigenous species than marine shrimp because of its alternate requirement for brackishwater and freshwater to complete its life cycle. Thus, freshwater prawns can only colonise a new habitat if escape occurs from farms located near the coast. In most temperate climates where *M. rosenbergii* has been introduced, water temperatures annually fall to lethal levels, which would prevent the establishment of wild populations. However, this is not the case in tropical conditions. Reports of populations of *M. rosenbergii* becoming established following escapes from farms in South America have been noted in Chapter 10. However, no adverse environmental impact has been documented so far (2000). In two States of Brazil these populations are being exploited through artisanal fishing.

The organic residues produced as a consequence of unconsumed feeds and the residues of fertilisers may be important pollutants. Generally, the effluent from freshwater prawn ponds is rich in nitrogen, phosphorus and solids (Valenti 1996). Suitable feeding and fertilising schedules, as well as the use of a stable aquafeed with a good feed conversion ratio (see Chapter 13) should contribute to minimising this kind of pollution. In addition, these effluents constitute a rich resource for agricultural use. Valenti (1996) recommended the use of effluents from freshwater prawn farming for the irrigation of crops (see section 23.1).

Methods of preventing the escape of prawns from grow-out ponds, and the treatment of effluent waters, as well as studies on the possible ecological impacts of the introduction of *M. rosenbergii*, are important fields for research. Meanwhile, 'the precautionary approach' should be utilised and compliance with international codes of practice and procedures which include guidance concerning the introduction and transfer of aquatic organisms (FAO 1997b) is necessary. In countries where *M. rosenbergii* is not indigenous, development of the culture of domestic *Macrobrachium* spp. should be encouraged if technical and economic viability can be demonstrated. Limited farming of other species of *Macrobrachium* occurs in Asia, South America and Africa (see Chapter 21). Production from the farming of *M. nipponense* in China is already substantial. Additional research and public funding is required to support the culture of indigenous *Macrobrachium* spp.

23.3 Ancillary benefits

Freshwater prawn farming has some ancillary benefits; the most notable of these is biological control. Lee *et al*. (1982) reported that *M. rosenbergii* preys on the two major South American schistosome vector snails (*Biomphalaria glabriata* and *B. tenagrophila*). New (1990) suggested that this foraging characteristic might prove useful if applied in Africa and South America, especially if prawns were reared with tilapia. According to Roberts & Kuris (1990), prawns greater than 22 mm in carapace size can consume snails of any size. More recently, Mahapatra & Datta (1996) noted that the introduction of *M. rosenbergii* into freshwater finfish ponds to control invasions of the molluscs *Lamellidens marginali*s, *Bellamya bengalensi*s and *Pila globosa* contributed to the economic returns of farms in the Sundarbans of West Bengal.

23.4 Conclusions

Some of the concerns that have been noted in this chapter are not specific to freshwater prawn farming. On the other hand, it has been argued, albeit without documentary evidence as yet, that freshwater prawn farming may be more environmentally and socially acceptable than marine shrimp farming. The culture of *Macrobrachium* has many characteristics that are the foundation of sustainable aquaculture. It certainly lends itself to the integrated use of resources for agriculture.

Research, training and commercial ingenuity are essential factors in expanding any form of aquaculture. The development of formulated larval feeds to solve the problem of inconsistent supply and high cost of *Artemia* cysts, the provision of funding for adequate environmental assessments, the establishment of product quality assurance schemes, and the development of diversified products to access specific market niches are just four examples of topics that would benefit the expansion of freshwater prawn farming.

If the industry structures itself to deliver good-quality products to the consumer through the use of socially and environmentally acceptable production methods, then further and substantial expansion of this sector of aquaculture is justifiable and realisable.

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